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OF THE
ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Hon. Fellow

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NOTICES

Suggested Amalgamation of the Institution of Aeronautical Engineers with the Royal Aeronautical Society

At a joint meeting held on June 30th, 1927, between representatives of the Royal Aeronautical Society and the Institution of Aeronautical Engineers, the following were present:—

In the chair, Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.

Representatives of the Royal Aeronautical Society.

Captain P. D. Acland.
Mr. Griffith Brewer.
Major A. R. Low.
Mr. F. Handley Page.
Mr. J. Laurence Pritchard (Secretary).
Colonel the Master of Sempill (Chairman).

Representatives of the Institution of Aeronautical Engineers.

Lieut.-Colonel Moore-Brabazon.
Mr. M. L. Bramson.
Mr. Howard Flanders.
Mr. N. J. Hulbert (Hon. Secretary).
Captain Lamplugh.
Squadron Leader Reid.
Mr. L. Wingfield.

An agreement on outstanding points was unanimously arrived at by the Joint Committee. This agreement afterwards came before the Council of the Society, who unanimously approved of it and recommended that the amalgamation should be proceeded with on the terms of the Beharrell report as amended by the meeting of June 30th, 1927. These terms are now under consideration by the Institution of Aeronautical Engineers, and their decision will be communicated as soon as it is known.

Powers of the Editor

The following is an extract from the Minutes of the Council held on July 12th, 1927:—

> "The Council authorised the Editor to cut out non-essentials of the discussions of papers, in order to save expense in printing the Journal."

Price of the Journal

In view of the increased size of the Journal, an increase which will be maintained in the future, the cost of printing exceeds its present price, 2s. 6d. The Council have therefore authorised that the price of the Journal shall be increased to 3s. 6d. per copy to non-members as from January 1st, 1928.

Reprint

The paper on "Valve Steels," delivered by Mr. P. B. Henshaw on December 2nd, 1926, has been reprinted, as the Journal containing it has gone out of print. The price is 10s. per copy, post free.

Elections

The following Members were elected at a Council Meeting held on July 12th, 1927:—

Associate Fellows.—Dr. A. Rohrbach, Mr. J. B. Prior and Mr. H. J. Stieger.

Members.—Captain S. Enosawa, I.J.A., Mr. Hudson Fysh.

Associate Fellowship Examination

Provided that a sufficient number of entries are received, the Society's examination for candidates not otherwise qualified for Associate Fellowship will be held during the third week in September. Intending candidates should forward their entry forms as soon as possible and in any case before the third week of August.

Felixstowe Visit

A very successful visit was paid to Felixstowe Air Station by Members of the Society on Friday, July 15th. The party was in charge of Mr. Griffith Brewer, a Member of Council, and among the interesting things seen were two of the entries for the Schneider Cup contest. Much of the success of the visit was due to Squadron Leader Maycock, who put every facility in the way to make it an enjoyable and interesting one.

Donations

The Council wish to thank Sir Mackenzie Chalmers and Major D. H. Kennedy for their gifts of back numbers of the Journal, and Colonel Mervyn O'Gorman for £1 towards an Entertainments Fund.

General Italo Balbo

On the occasion of the brief visit of General Italo Balbo, the Italian Under-Secretary of State for Air, the Royal Aeronautical Society, the Royal Aero Club, the Air League and the Society of British Aircraft Constructors entertained His Excellency to lunch at the Savoy on July 5th, 1927. The following letter has been received by the Chairman of the Society from General Guidoni:—

Dear Master of Sempill,

On behalf of His Excellency General Balbo I have pleasure in forwarding you his best thanks for the many courtesies extended to him during his visit to London. May I add my personal thanks to you? You have been very kind in helping me in the circumstances, and I only hope that your coming to Venice next September may enable us to return you at least part of your courtesies.

Yours very sincerely,
(Signed) A. Guidoni.

Colonel Charles A. Lindbergh

The following letter was inadvertently omitted from the July issue of the Journal:—

American Embassy, London,
2nd June, 1927.

Dear Colonel the Master of Sempill,

I am writing to you as Chairman of the Royal Aeronautical Society in an endeavour to express my thanks for the overwhelming and generous reception I have received from the people interested in aeronautics in England.

Through you and the governing Council of the Royal Aeronautical Society I should like to take this opportunity of thanking not only the Society, but those other bodies which together govern the field of British aeronautics:—

The Royal Aero Club,
The Air League of the British Empire and
The Society of British Aircraft Constructors.

All four bodies have shown such great interest in my flight, and given me personally such a welcome on the occasion of my all too brief stay in this country, that I feel convinced that the bond of aviation is binding Great Britain and America more closely together than ever before, and that it will strengthen with the years to come.

The spontaneous sincerity of your welcome makes me hope that in the not very distant future I may be able to re-visit your country and renew the all too brief acquaintanceships.

Yours sincerely,

(Signed) CHARLES A. LINDBERGH.

Italian International Air Congress

On the invitation of the Italian Government and under the Presidency of His Royal Highness the Prince Amedo di Savoia Aosta, the Fourth International Air Congress will be held in the Main Hall of the Reale Accademia dei Lincei in Rome on October 20th-26th, 1927. Meetings will be held on air navigation questions, scientific and aerological questions, legal questions, medical questions, technical questions and touring and propaganda during the five days following the opening of the Congress. All members participating in the Congress will receive special reduced travelling fares and other facilities in Italy. Members wishing to submit written papers should do so by September 1st. The official languages of the Congress are Italian, French and English.

Further particulars may be obtained from the Secretary-General, Major Pier Francesco Bitossi, IV International Air Congress, Via della Mercede, 9, Rome.

J. LAURENCE PRITCHARD, *Secretary.*

OBITUARY

WING COMMANDER WILLIAM GEORGE SITWELL

It is with great regret that we have to record the death of Wing Commander William George Sitwell, at the early age of 37, in the R.A.F. hospital at Halton.

Wing Commander Sitwell, a Member of the Society, took his Aero Club certificate in June, 1913, and so was one of the pre-war pioneers of flying. He was a brilliant all-round airman, but his constant ill-health prevented him from rising as high in the Service as his abilities entitled him to.

WILBUR WRIGHT MEMORIAL LECTURE, 16th MAY, 1927

The Fifteenth Wilbur Wright Memorial Lecture was delivered under the auspices of the Royal Aeronautical Society by Dr. Prandtl on Monday, May 16th, 1927, in the Theatre of the Royal Society of Arts, Adelphi.

In introducing the Lecturer, Colonel the MASTER OF SEMPILL, Chairman of the Society, said: This Society is justly proud of the fact that it has the unique distinction of being the oldest aeronautical body in the world. It is very rightly jealous of its position and careful to maintain the highest standard in its lectures and many other activities.

The Wilbur Wright Memorial Lecture is by far the most important of the Session, filled though each may be with lectures delivered by personages of authority in this and other countries.

It would be impossible for me to add lustre to the name of that great pioneer Wilbur Wright, nor is any wordy tribute necessary. He was a man of many deeds and few words and so the best tribute to his memory is to follow his example by striving to develop the science of aeronautics and to widen the applications thereof. As St. Matthew said: "By their works ye shall know them." It is appropriate that those in authority in this country should have at last commenced to show the world at large what British aircraft are really capable of. I refer of course to the non-stop flight that would have been attempted this morning had the weather been suitable. Perhaps better very late than never at all.

The first Wilbur Wright Memorial Lecture was delivered in 1913. Since then we have had fourteen such lectures, ten by British and four by Americans. It is only right that the field from which lecturers can be drawn should be as wide as possible since Wilbur Wright did not work only for the advancement of aeronautics in Great Britain and America. The Council therefore came to the conclusion that Professor Prandtl, of Göttingen University, whose name has been a household word in aeronautical circles for many years past, should be invited to give this lecture.

A word or two on Professor Prandtl's work may not be out of place.

We often observe real fluids with internal friction, such as air or water, disturbed by the sudden movement of an immersed body. The motion of the fluid in the first instant is the same as the motion predicted mathematically of a perfect fluid without internal friction, excepting for a thin layer near the surface of its body (or the surface of the enclosing walls). This layer is produced by the frictional forces which are great very near to the walls but negligible elsewhere.

After the first instant the layer grows rapidly in thickness and becomes unstable, breaking up with the formation of eddies which mix the fluid thoroughly. No mechanical process can unmix this mixture.

These phenomena are of fundamental importance in our daily life. Without the formation and instability of the boundary layer we should take back into our lungs at each breath the same air substantially that had just been breathed out and should asphyxiate ourselves in a few minutes. Great towns would suffer from their own carbonic acid gas in a way of which we get a slight hint from our famous London fogs. Birds and fish, totally immersed in air and water,

would be unable to swim or fly; on the other hand, a fish or a torpedo once set in motion would travel for miles without power. Web-footed creatures and row boats would progress more quickly and easily by setting up the familiar semi-circular vortices with air-filled cones ending on the surface; under these conditions a University eight, opposed only by wave-making resistance, would easily beat all records. Marine screws would propel ships faster than ever if just the right amount of air was supplied to fill the cones of the spiral vortices trailing from the blade tips. A great English experimenter, Osborne Reynolds, who discovered a fundamental physical quantity—Reynolds' number—recurring constantly in to-night's paper, first employed systematically in 1877 devices for rendering fluid motion visible (by injecting coloured jets, etc.) and found "eddies everywhere," particularly in the cases mentioned above. He made many fundamental advances and laid the foundations for subsequent work; but conscious of limitations, he expressed the hope that mathematicians would set aside "a certain pride in mathematics" and study, visually, the motion of real fluids, so as to develop appropriate applications of mathematical analysis.

We have had to wait for Professor Prandtl to realise this forecast of Reynolds with any substantial degree of success. From his paper in 1904 he has advanced steadily in the task of observing and explaining the mechanism of the most varied fluid motions. To-night he will give us a descriptive account, with illustrations by photograph and cinematograph record, of the formation and break up of this remarkable layer of fluid—the "Prandtl boundary layer" as it is now generally called after him—and we shall see how profoundly the whole nature of the flow is affected by what at first sight seems a trivial circumstance.

Much remains to be done, and it may even be said that new mathematical methods must be developed; but we have already, through Prandtl's work, an insight, denied to the greatest men of science in the past, into many phenomena of fluid motion and, of especial interest to this Society, into the phenomena of flight.

The Council have decided to confer on Professor Prandtl the highest award that the Society can make, viz., the Gold Medal. This unique award has only been made five times, being first conferred on Wilbur and Orville Wright in 1909. Last year, as you will probably recall, it was conferred on Dr. Lanchester, who is with us this evening and whose work is referred to in very complimentary language in Professor Prandtl's paper. The Council have also conferred on Professor Prandtl Honorary Fellowship of the Society.

Colonel the Master of Sempill at this point turned to Professor Prandtl and said: It is my special privilege to hand to you, on behalf of the Royal Aeronautical Society, the Gold Medal and the Diploma of Honorary Fellowship, which have been conferred upon you in recognition of your immense contributions to the science of aeronautics.

I have one other extremely pleasant duty to perform and that is to present the Society's Silver Medal, which is awarded each year for the best paper published in the Journal.

The Council have unanimously decided to award this medal for 1926 to Professor Melvill Jones for his paper entitled, "The Control of Stalled Aeroplanes." I am quite sure that this will meet with universal approbation as Professor Melvill Jones's contributions, both theoretical and practical, to aeronautics are considerable and have been recognised in an enthusiastic manner in this and other countries.

Professor PRANDTL, on receiving the gold medal, said: Mr. Chairman, My Lords, Ladies and Gentlemen,—You have conferred on me the highest honours your ancient and celebrated Society can bestow. You have thus rewarded my scientific work by such high approval that I hardly know how to thank you.

Perhaps the best way of showing my gratitude will be to continue to the best of my power to advance aerodynamical science.

Professor Prandtl then read the beginning of his lecture, the reading of which was completed by Major A. R. Low.

THE GENERATION OF VORTICES IN FLUIDS OF SMALL VISCOSITY

BY DR. L. PRANDTL.

MR. CHAIRMAN, MY LORDS, LADIES AND GENTLEMEN,

You have invited me this year to deliver the Wilbur Wright Memorial Lecture. It is the first occasion, I believe, upon which you have selected a lecturer from outside Anglo-American circles, and I can assure you that I fully appreciate the great honour conferred upon me by your selection. As I was not very familiar with the English language, I had considerable misgivings at first as to accepting the invitation, but it was obvious to me that I had to justify the confidence you had placed in me and I therefore decided to accept, and to accept with great pleasure. Only I must ask you to be so kind as to extend to me your indulgence when you hear a word badly pronounced or wrongly accented.

In choosing the subject matter of the lecture I did not think it appropriate to speak on my contributions to aerofoil theory because it is already familiar to you in England through the numerous papers read before this Society, and the publications of the Aeronautical Research Committee here and in the United States of America. You have also the reprint of Mr. H. M. Martin's lucid exposition in *Engineering*, 1924, and Mr. H. Glauert's excellent textbook published by Cambridge University Press, 1926.

I thought it would be preferable to select another subject with which you are possibly less familiar in England, although its beginnings go further back than do those of the aerofoil theory. I will refer to the generation of vortices in fluids of small viscosity by the action of the boundary layer. Froude was the first English writer to refer the frictional resistance of a flat plate to the layers of fluid in intense shear near the surface. Lanchester developed an approximate theory for steady laminar flow. Professor Bairstow read a paper in 1924 to this Society on the subject and gave our results for steady laminar flow. But the conclusions I showed in 1904 from the existence of the boundary layer to the formation of vortices, are apparently not so well known here. I noticed, indeed, recently that the most important discussions of this theory have been briefly referred to in Glauert's book just mentioned, so that possibly you are not quite so unfamiliar now with that theory in England as a little while ago.

Before proceeding to the lecture proper, however, you will allow me to make two brief observations on the aerofoil theory. Firstly it is my duty to thank the English experts for the great and lively interest they have taken in this theory and for the very considerable efforts they have devoted to the testing out of the theory by means of experiments in the most diverse directions. Then to say a word on the origin of the theory. In England you refer to it as " the Lanchester-Prandtl theory," and quite rightly so, because Lanchester obtained independently an important part of the results. He commenced working on the subject before I did, and this no doubt led people to believe that Lanchester's investigations, as set out in 1907 in his " Aerodynamics,"

led me to the ideas upon which the aerofoil theory was based. But this was not the case. The necessary ideas upon which to build up that theory, so far as these ideas are comprised in Lanchester's book, had already occurred to me before I saw the book. In support of this statement, I should like to point out that as a matter of fact we in Germany were better able to understand Lanchester's book when it appeared than you in England. English scientific men, indeed, have been reproached for the fact that they paid no attention to the theories expounded by their own countryman, whereas the Germans studied them closely and derived considerable benefit therefrom. The truth of the matter, however, is that Lanchester's treatment is difficult to follow, since it makes a very great demand on the reader's intuitive perceptions, and only because we had been working on similar lines were we able to grasp Lanchester's meaning at once. At the same time, however, I wish it to be distinctly understood that in many particular respects Lanchester worked on different lines than we did, lines which were new to us, and that we were therefore able to draw many useful ideas from his book. The

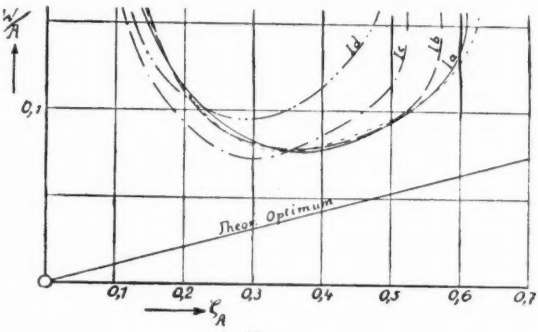


FIG. 1.
Prandtl-Betz 1914.
Curves Ia-Id = experiments; straight line = formula.

volume published in 1915 (Lanchester—"The Flying Machine." Two papers, "The Aerofoil and the Screw Propeller." Reprint from Proceedings of the Institution of Automobile Engineers, Vol. IX., London, 1915, pages 32 to 35), in which Lanchester comes to the same conclusion with regard to the induced drag as we did, was unknown to us until 1926. As it happens, the same formula was published by us in 1914 (Betz, *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, 1914, page 239 and Table VIII.) together with an almost similar graphical representation (drag/lift, plotted against the lift coefficient, the induced drag being shown by a straight line through the origin, see Figs. 1 and 2).

I.

And now to proceed to our actual subject. The first question might well be the following. How are we to reconcile the rapid formation of intense vortices in a fluid of very small viscosity, as everywhere observed, with Lagrange's theorem that no element of a perfectly inviscid fluid originally at rest can be brought into a state of rotation? We must surely assume that if we regard the viscosity of the fluid as continually diminishing, the state of motion approaches that of the non-viscous fluid more and more closely. Observation, however, teaches us otherwise. The viscous forces within a fluid flowing round any body, say a ball or a cylinder, amount frequently to only one-ten-thousandth, or even to only one-millionth part of the forces of inertia appearing at the same point, so that the results of the theory of the perfectly frictionless or non-viscous fluid

should apparently hold good. What have we to say about this paradox? How are we to account for the contradiction?

Before answering this question, let me first of all refer to a very important theorem originally propounded by the late Sir William Thompson (Lord Kelvin) and one which might well serve as a foundation for the hydrodynamics of frictionless or non-viscous fluid. Before quoting the theorem, I should like to give some explanatory references. Let us suppose a "fluid line" to be a line composed permanently of the same fluid particles. The line-integral of the velocity we will take to be the sum of the elementary arcs of the line each multiplied by the component of the speed in the direction of the element, the mathematical expression being $\int v \cos \alpha \, ds$. We have to deal, therefore, with the same mathematical device which in a field of force gives the work done along the line. *Circulation* is the name we give to the line-integral of the velocity round a closed circuit. The circulation, therefore, gives the strength of the cyclic motion of fluid flow. (According to Stokes, this is equivalent to the sum of the strengths of the vortex tubes enclosed in the circuit.) Having given these definitions, we can now enunciate Kelvin's theorem, namely, that *in a homogeneous, frictionless fluid the circulation around every closed fluid line is invariable in time.*

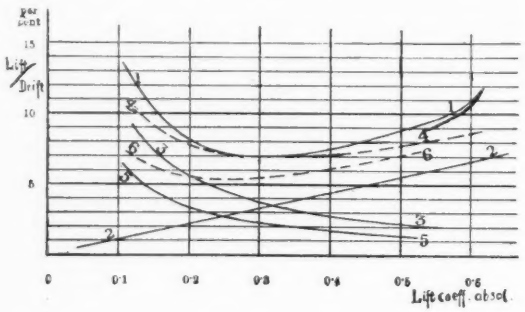


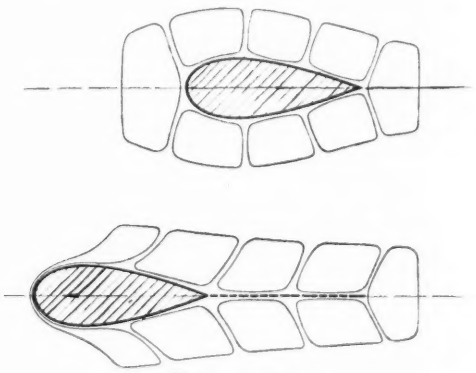
FIG. 2.

Lanchester 1915.

Curve 1-1, *experimental; line* 2-2, *formula.*

From this theorem we can draw the following conclusion:—If the whole of the fluid is initially at rest, then the circulation round any imaginable circuit is zero, since the velocity is everywhere zero. The Kelvin theorem requires that for each of these circuits the circulation must be zero at all subsequent times. We can, if we like, imagine the fluid at rest to be subdivided by an arbitrary network with small meshes each forming a small circuit. The premiss that the circulation round every one of these small circuits remains zero, leads evidently to the conclusion that rotation cannot appear anywhere. It will be seen, however, that this conclusion is premature. We must first ascertain whether every point of the fluid set in motion is actually enclosed by the lines which in the state of rest were closed, if our conclusion is to be permissible. But closer investigation shows that it is possible to give instances in which this is not the case. In these examples there is always the question of a confluence of previously separated fluid elements. None of the closed fluid lines cross the surface which separates the confluent fluid elements, and the Kelvin theorem says nothing about the continuity of velocity across this surface. The Figs. 3, 4 will show this process more clearly. The upper diagram represents a body with a network of circuits in

the surrounding fluid at rest. Now let the body be moved to the left, so that the upper and lower streams flow together, or as we shall say become confluent, at the sharp rear edge of the body. We can see in the lower diagram that the network of closed circuits is divided by the surface of confluence, along which our conclusion as to the absence of vorticity is no longer applicable. The mass of fluid may remain continuous, as shown in the figure, but discontinuities of velocity, that is to say, vorticity concentrated in a sheet, will arise. It is this process of confluence which in the case of aerofoils allows of the formation of the circulation around the wings, together with the vortices behind it, necessary for setting up the lift. Here I shall explain only the initial stages of the motion from a state of rest for a wing of infinite span (Fig. 5). During the accelerations, the velocity at the rear edge is greater on the pressure side than on the suction side, since the path along the pressure side is shorter. Consequently, after confluence a discontinuous distribution of velocity is set up which effectively constitutes a sheet of intense vorticity; the surface of discontinuity then begins to roll up into a spiral. The circulation for each circuit enclosing the wing and the surface of discontinuity still remains zero, from which it may be inferred that the circulation around the wing is equal and opposite to the circulation of the vortex pro-



FIGS. 3 AND 4.

duced by rolling up of the sheet. This is the method of generation of the circulation around the wing. In steady mean flow the surfaces of discontinuity from wings and propellers are familiar to everyone. The next picture (Fig. 6) shows you the surface of discontinuity of a wing which for the purpose of theoretical investigations is usually replaced by a somewhat simplified distribution of vorticity. The same thing applies equally to propellers.

We may sum up the gist of the conclusions established as follows:—"*Every confluence at sharp edges can, without contradicting Kelvin's theorem, give rise to a surface distribution of vorticity—a vortex sheet.*" I can certainly see the mathematician raising the objection that the flow with confluence at the edge is not the only possible flow, but that in the case of an inviscid fluid there is also possible a flow around the edge and that the solution of the flow around the edge is the correct one, because it is everywhere irrotational in accord with the theoretical laws for a flow produced from a state of rest! Well, it must be admitted that this solution without vorticity, but with the flow around the edge is mathematically quite in order. But what about the physical condition? When there is a flow around an edge, the mathematical expressions lead to infinitely high speeds and to infinitely high negative pressures at the edge. We cannot, therefore, believe that such a distribution of velocity can really exist. In

the case of water, at zero pressure, separation of the dissolved air and evaporation of the water ensues; in the case of air, rapid expansion takes place. Both processes hinder the setting up of indefinitely great negative pressure and, consequently, prevent flow around the edge. Presently, however, we will see that viscosity, however small, has a similar effect and that generally long before there is any rupture or expansion a motion is set up in which the high speeds are avoided. In setting up the state of motion from rest there is indeed an initial instantaneous flow around the edge corresponding to the mathematical theory, with relatively

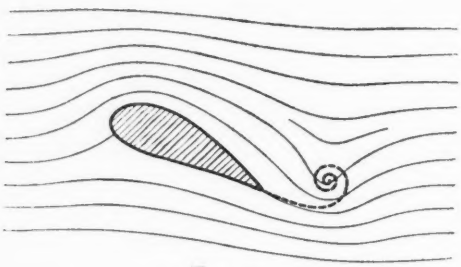


FIG. 5.

high speeds at the edge, but immediately afterwards a vortex is formed which increases continuously by the rolling up of the surface of vorticity trailing from the edge. If we do not wish to go more into detail concerning the frictional processess, we can simply treat the fluid as being frictionless, as is done for example in the aerofoil theory. In order, however, to justify the physical facts, we must lay down that the speed at sharp edges remains finite in all cases and that in order to maintain this finite velocity a surface of vorticity is formed at the sharp edge.

II.

Observation teaches us that sharp edges are by no means necessary for the formation of vortices in a slightly viscous fluid, but that, shortly after the inception of the motion, vigorous vortices appear also behind continuously curved bodies, such as circular cylinders. These phenomena have also been elucidated in

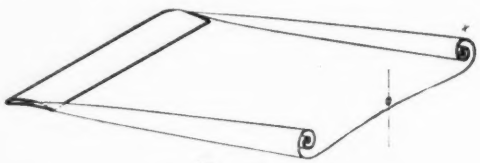


FIG. 6.

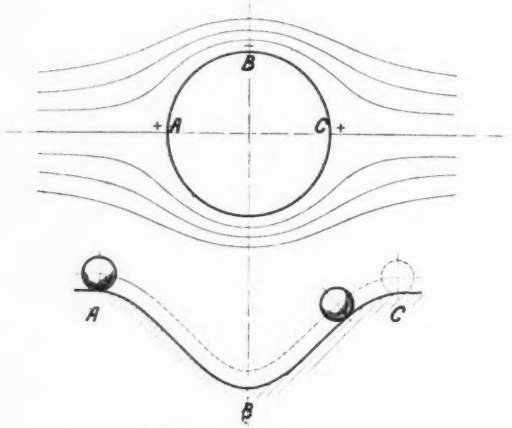
a far-reaching manner and I shall, therefore, proceed to explain to you the conditions prevailing therein. If we investigate more closely the flow of a viscous fluid, that is to say, of a fluid endowed with internal friction, we find first of all that the layer of fluid lying directly on the surface of an immersed body adheres to the body, that is to say, suffers no displacement relative to the body. The layers lying immediately above slide over the body at speeds increasing with their distance from the rigid surface. But what are the conditions when we regard the viscosity as becoming smaller and smaller? In this case, too, the layer lying immediately next to the obstacle adheres, whilst the elements more distant

from the obstacle move practically as if inviscid. In the case which we must consider especially of irrotational motion (potential motion), the forces of the internal friction are substantially in equilibrium with themselves, so that the motion in a velocity field in which it is present is not modified by the frictional force. In a fluid with slight viscosity the transition from the outer flow in which inertia only is effective, to the adhesion at the boundary, takes place in a thin layer in which inertia interacts with friction. If the viscosity decreases, the layer simply becomes thinner, but remains otherwise of the same nature. Thus, in every flow of a slightly viscous fluid the obstacles present in the flow are covered with a thin layer, the motion of which has been retarded by friction. The calculation can be carried out more or less exactly in many cases and shows that the thickness of the layer is in inverse proportion to the square root of the viscosity. More precisely, the proportion of the thickness of the layer to the diameter of the obstacle is inversely proportional to the square root of Reynolds' number. To this frictional flow corresponds a frictional drag that appears in the form of tangential forces on the surface of the obstacle and is proportional to the $3/2$ power of the speed and to the square root of the viscosity ($D_f = \text{Number} \times \sqrt{\mu \rho l^3 v^3}$). But there is something of more importance to us here. The frictional layers, the so-called boundary layers, are *the cause of the formation of vortices*. If we bear in mind that the Kelvin theorem applied only to flow devoid of viscous forces, we can establish the fact that in the case of motion starting from a state of rest the circulation will remain practically zero in those fluid circuits of which no part passes or, during the course of the motion, has passed into a boundary layer. In other words, in a slightly viscous fluid, fluid elements which have nowhere come sufficiently near the body will behave according to the theory of inviscid fluids, and in particular will move irrotationally. Fluid elements, however, which have come into proximity with the obstacle will generally exhibit rotation afterwards. We can now see that layers of very small but finite thickness play the same part which we have already ascribed in the previous section to surfaces of confluence; we now have *layers* of vorticity, instead of *surfaces* of vorticity. This difference affects but slightly the general behaviour of the fluid, so that no serious error will be made if in the case of flow behind sharp edges viscosity is totally neglected, but the study of the subject will be very much simplified. It should be noted, however, that layers of vorticity, like surfaces of vorticity, are to a very high degree unstable and show a tendency to break up into individual vortices as soon as waves or undulations are formed in them by accidental disturbances (see Fig. 7 which shows the development of vortices from waves); a flat wave becomes steeper owing to its unstability, rolls over on itself and becomes a vortex.

FIG. 7.

Owing to these processes, fluid elements coming from the boundary layer and consequently exhibiting rotation, are distributed in some strength through the wake, which thus acquires a markedly turbulent character.

In order to understand the phenomenon already referred to, that vortices are formed at an obstacle not having any sharp edges (*i.e.*, that sheets of vorticity trail from the immediate neighbourhood of the obstacle into the fluid), we must examine the mechanism of the flow at the obstacle somewhat more closely. If we consider a circular cylinder, then according to our assumption (confirmed by experiment and also by hydrodynamic theory) a potential flow in accordance with the ordinary theory of the perfect fluid will first of all ensue. In this flow, as Fig. 8 shows, the fluid divides at A and becomes confluent again at C. The velocity is zero at A, as also at C, and a maximum at B. The pressure is accordingly a maximum at A and C and a minimum at B. Each element of fluid flowing from A to B attains its speed from the fall of pressure prevailing between A and B. Its kinetic energy is then just sufficient to allow the particle to reach the point C against the increase of pressure pre-



FIGS. 8 AND 9.

vailing between B and C; the conditions are quite analogous to that of a ball on a smooth path which, starting from a wave crest with a speed of zero, is just able to attain a second and equally high point (Fig. 9). If this ball, however, were to experience any friction along its path, it would no longer be able to reach the second point, but would, before reaching it, turn back again. And precisely this must be the fate of the portions of the thin layer which have been retarded by the friction on the surface of the obstacle. Where the fall of pressure is in the direction of the flow, the retarded portions also move forward and nothing special can happen here. If the direction, however, of the fall of pressure is opposed to the direction of the flow, the kinetic energy of the retarded portion will not suffice to allow of its reaching the deadwater point C and a return current is produced. Since more retarded fluid is being continually added and suffers the same fate, a steadily increasing accumulation is formed between B and C which sets itself into motion towards the region of minimum pressure and pushes away the outer current with formation of a vortex. The form in which this takes place is again that of "confluence." The flow is completely transformed and a configuration is set up in which the space behind the obstacle is filled by a comparatively slow-flowing and, in general, irregularly eddying vortical

motion, whilst the flow approaching from the front leaves the boundary at somewhat behind the point of minimum pressure (which now lies in another position).

Transition from this case to the case of more or less sharp edges is usefully made by establishing the fact that the formation of the first vortex takes place after a relative displacement of the body of the same order of magnitude as the radius of curvature of the boundary at the point where the line of confluence leaves it. If we make this radius of curvature smaller and smaller, the curved end will gradually pass into an edge; at the same time the relative displacement in question will become very small. With a sharp edge, the formation of the vortex will begin instantaneously.

The mathematical theory of these phenomena at curved surfaces can be developed in a satisfactory manner in the first stage of the formation of a vortex (see H. Blasius, *Zeitschrift für Mathematik und Physik*, Vol. 56 (1908), pp. 1 *et seq.*), but is still wanting in the case of flow around a sharp edge, so that we must be content meanwhile with this process of approaching the limiting case.

I will now show you some photographs illustrating the phenomena which we have been discussing.

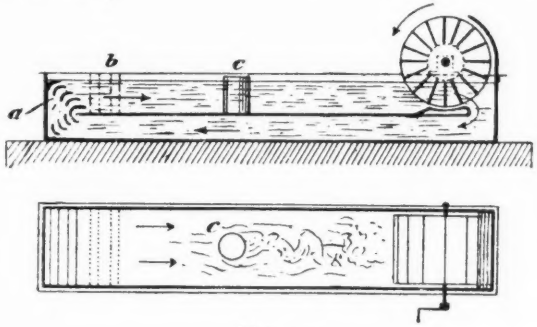


FIG. 10.

The first of these date back to the year 1904, when I exhibited them at the International Mathematical Congress at Heidelberg (see *Verhandlungen des dritten Internationalen Mathematiker-Kongresses*, Leipsic, 1905, page 484), and *Vier Abhandlugen zur Hydrodynamik und Aerodynamik* (four papers on hydrodynamics and aerodynamics by Prandtl and Betz, Göttingen, 1927, page 1). The experiments were carried out in a small channel, Fig. 10, in which the water could be set in motion by means of a paddle wheel. In order to render the flow visible to the naked eye use is made of a mineral consisting of microscopically small, reddish and very lustrous scales. In Germany it is called " Eisenglimmer " (micaceous iron ore). Where the water undergoes rapid strains the scales are oriented, and exhibit a striking lustre by means of which the vortices are easily recognised. The first two photographs (Figs. 11 and 12) show the formation of vortices at sharp edges. We can recognise the growth of the vortex and also its collapse from instability. Figs. 13 and 14 show the same process. In Fig. 14 we have the type of motion finally set up. It can be seen that an eddy region is established upstream in consequence of the accumulation and breaking up of a layer of retarded fluid along the channel wall.

The next two photographs (Figs. 15 and 16) show flow round a curved vane. The dark band is merely the shadow of the vane on the surface of the turbid fluid. An eddy has formed inside the dipping front edge. From the sharp tail flows a confluent sheet which rolls up into individual eddies. The initial vortex can be seen just leaving the figure and is clearly three or four

times the diameter of the following vortices. On the upper surface near the tail a process of backflow is seen to be setting in. In Fig. 16 the backflow has further developed and the upper stream is seen to be leaving the surface.

The next four photographs (Figs. 17, 18, 19, 20) show flow round a circular cylinder. In the first photograph the commencement of the motion is shown. Ignoring the residual effects of earlier disturbances, the flow back and the beginning of the formation of a vortex pair is seen. In the next photograph the process has gone further; in the third the vortices are becoming unstable; and in the fourth the final type of motion is seen. In the first three photographs it is seen that a well defined straight narrow band streams behind the cylinder. This contains the portion of the boundary layer which was carried down stream from the cylinder before the vortices began to form. It is a sheet of confluence without circulation.

Later on, we obtained photographs (showing the streamlines) by the method of Professor Ahlborn, of Hamburg, by sprinkling small particles of lycopodium, or aluminium powder on the surface of the water.

The next set of six photographs (Figs. 23, 24, 25, 26, 27, 28) show the configuration of flow past a circular cylinder recorded by this method. The camera is mounted on a carrier which travels with the cylinder so that the photographs record the streamlines with reference to a system of axes of reference fixed in and moving with the body.

Photographs were taken by us in this manner as long ago as 1914, but I am showing you our latest photographs taken a few weeks ago with much improved technique.

The first of this set (Fig. 23) shows the instantaneous motion at the beginning with potential flow past the cylinder. An effect of surface tension is seen in the accumulation of aluminium particles on the surface of the water where it is in contact with the cylinder, forming a bright belt. And as the fluid elements in the neighbourhood of the body are those which later form the surface of confluence, that is the sheet of vorticity, these portions are brighter than the rest in the following photographs and show the vortex sheets.

The next photograph (Fig. 24) shows the accumulation of the retarded fluid behind the cylinder and the commencement of the back flow. The "dam" point is perceptibly behind the cylinder. In the third of the series (Fig. 25) two symmetrical sheets of confluence are leaving the surface and beginning to roll up into vortices. In the fourth of the series (Fig. 26) the rolling up is very complete, for the back flow produces itself the conditions for the formation of secondary vortices rotating in the opposite direction to the parent vortices. In the fifth of the series (Fig. 27) many secondary vortices have been formed and passed downstream along the main vortices which they render more and more irregular. The undulations at the rear of the main vortices denote the presence of secondaries. In the sixth and last of this series the final type of flow is shown in which the whole wake is oscillating.

The next set of five photographs show the process of setting up circulation round a wing (Figs. 29, 30, 31, 32, 33), the first three with respect to axes carried in the body, the last two with respect to axes at rest respective to the undisturbed fluid. In the first (Fig. 29) there is potential flow everywhere except at the sharp tail where the formation of an eddy commences instantaneously with the motion. The surface of confluence is beginning to leave the tail. In the second of the set (Fig. 30) the initial vortex has passed down stream and the sheet of confluence is drawn out after it. In the third (Fig. 31) the process has developed still further. The next two photographs show the same motion taken with a camera at rest. Fig. 32 shows the initial motion, and the last of the series (Fig. 33) shows the motion after the initial vortex has been thrown off and has passed some distance downstream while the circulation flow round the cylinder

and the discontinuity of the velocity at the vortex sheet can be clearly seen. Later this will be shown on a film.

III.

Means are available for preventing the formation of vortices and the consequent separation of the stream from the obstacle. Our theory indicates the method of so doing. Thus, for example, the accumulation of retarded fluid can be prevented by sucking the retarded layer into the interior of the body at points where the back flow would be set up. By this means the consequences of this accumulation are avoided and the stream follows the boundary continuously. I had already made an experiment of this nature in 1904 and here is the result (Fig. 36). The cylinder is provided with a slot; water is drawn off from the interior of the cylinder by means of a rubber tube which acts as a syphon and an equal quantity of water flows into the cylinder through the slot. And now a vortex is actually formed only on the side from which retarded fluid had not been drawn off; for now conditions for the formation of the back flow are set up only at the boundary opposite to the slot.

It may be remarked that here a surface of confluence leaving the channel wall with formation of a vortex begins to appear on the side of the slot.

The next photograph (Fig. 35) shows the final state of motion. The flow follows the boundary of the cylinder near the slot, but has left the cylinder on the opposite side and also the wall on the side of the slot. A transverse force is associated with this configuration of flow.

In the next set of three photographs (Figs. 36, 37 and 38) we have some new photographs showing a constricted canal which widens out again and has slots in the widening. When the slots are not in use the usual jet is formed. When the slots on one side are in use the flow follows this side. When the slots on both sides are open a flow is set up which is quite free from vortices, an unwonted appearance to those familiar with the usual motion of fluids. I should like also to refer to the fact, that by similar means we were able to bend an air flow round a body with a very small radius of curvature through 180°, without leaving the boundary (J. Ackeret, *Zeitschrift des Vereins deutscher Ingenieure*, 1926, page 1153, and *Verhandlungen des zweiten internationalen Kongresses für technische Mechanik zu Zürich* (Transactions of the Second International Congress for Technical Mechanics held at Zurich), 1926).

A further method for preventing the formation of vortices is to make the surface of the obstacle move with the fluid current. In this case there is no retardation of the flow, consequently there is no fluid material from which a vortex could be formed. This applies to the case of two cylinders rotating in opposite directions, and we thus obtain flow round a body without the throwing off of any vortices. The photographs, Figs. 39 and 40, are of historical interest, 1906-1907. In the first with the two cylinders the separation of the stream from the walls and the confluence in the middle may be noted. The sheet of confluence along the line of symmetry behind the cylinders behaves in a manner differing markedly from the previous examples. It appears to act like a jet and becomes unstable with formation of little vortices. It is, in effect, a jet, the boundary layer having been accelerated by the rotating surfaces in comparison with the surrounding fluid. Again, in the case of a single rotating cylinder (see Fig. 40), no vortex is formed on that side on which the direction of the current coincides with that of the rotation. The vortex on the opposite side, however, develops vigorously and gives rise, in compensation, to an equal and opposite circulation round the cylinder and consequently also to a cross force.

This is better shown in the next set of five photographs (Figs. 42, 43, 44, 45 and 46) which are enlarged from a film. Fig. 42 shows potential flow at the

beginning; Fig. 43 where confluence appears on one side only; Fig. 44 where the vortex is formed; Fig. 45 where the vortex is carrying downstream; and Fig. 46 the final stage after the vortex is gone away, leaving a remarkable circulation round the cylinder.

If, as in this example, the angular velocity of rotation is sufficiently great, the circulation can be increased to such an extent that flow actually encloses the cylinder. In this case the flow everywhere follows the boundary and no vortices are now formed. In this condition there is a very large transverse force. Flettner takes advantage of this in his rotor ship.

A third possibility, that of rendering the braked fluid of the boundary layer innocuous, consists in allowing the more rapidly flowing fluid to pass through a slot and to push the retarded fluid from the wall and again accelerate it. An example of this process is furnished by the slotted wings of the Handley Page and Lachmann type by means of which, as you all know, much greater maximum lifts can be attained than is possible with ordinary wings.

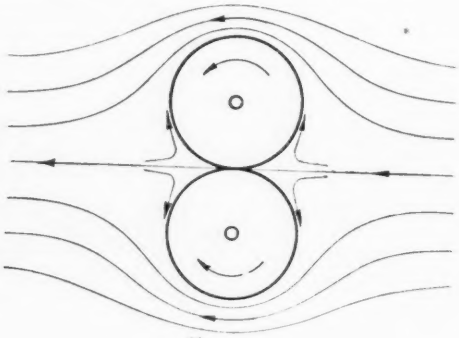


FIG. 41.

IV.

These statements would be incomplete without a reference to a phenomenon which has the effect of preventing or postponing the separation of the flow from the boundary. This phenomenon is of very great technical importance. It was observed first of all in the case of spheres, and then of cylinders and other bodies; with large Reynolds' numbers, 100,000 to 300,000, there is a somewhat sudden diminution in the resistance coefficients to about one-fourth of the value with lower Reynolds' numbers. Observation shows that the point where the current leaves the boundary is pushed far back and that the pressure distribution approaches that of the theoretical frictionless current. The explanation was that the boundary layer at the body becomes *turbulent*. Owing to this, there appears a rapid intermixture of the frictional boundary layer and the outer flow which accelerates the frictional layer again and thus prevents the separation of the flow from the boundary or at least postpones it. That this is the correct explanation I was able to prove in the case of the sphere, by fixing a wire hoop on the sphere which rendered the boundary layer vortical (see L. Prandtl, *Der Widerstand von Kugeln. Nachrichten der Gesellschaft der Wissenschaften zu Göttingen*, 1914, page 177). By this means I was able to obtain small resistance coefficients even when the Reynolds' numbers were fairly low. The last two photographs show the flows behind a sphere with and without the wire hoop. Smoke was also directed into the vortex region. The difference in size of the vortex regions can be seen from the two photographs; it is much smaller in the case of the sphere with the wire hoop. The turbulence is

FIG. 11.

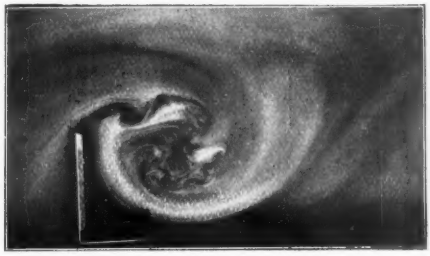


FIG. 12.

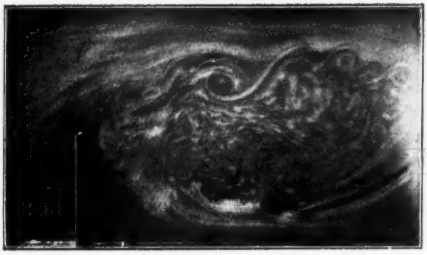


FIG. 13.

FIG. 14.

FIG. 15.

FIG. 16.

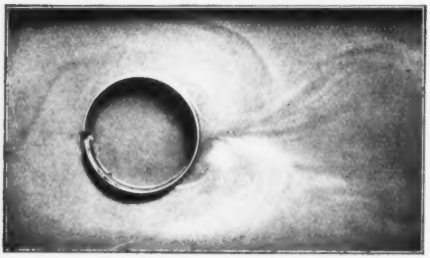


FIG. 17.

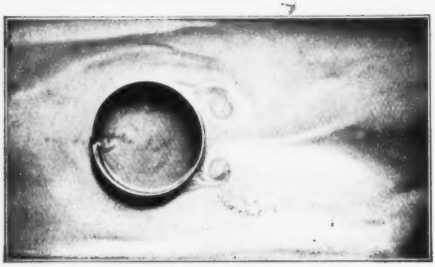


FIG. 18.

FIG. 19.

FIG. 20.

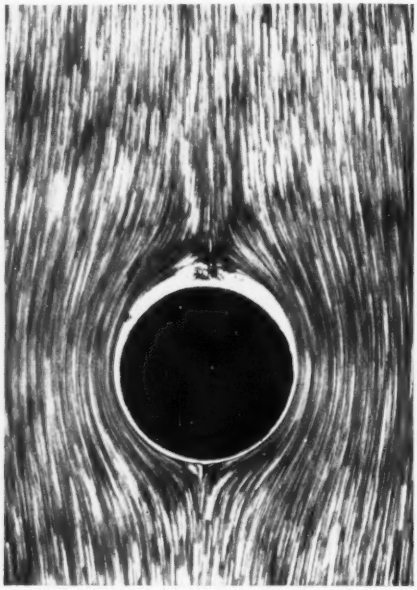


FIG. 24.

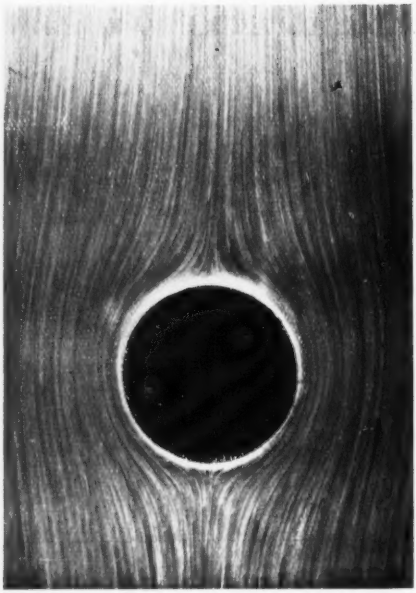


FIG. 23.

FIG. 23.

FIG. 24.

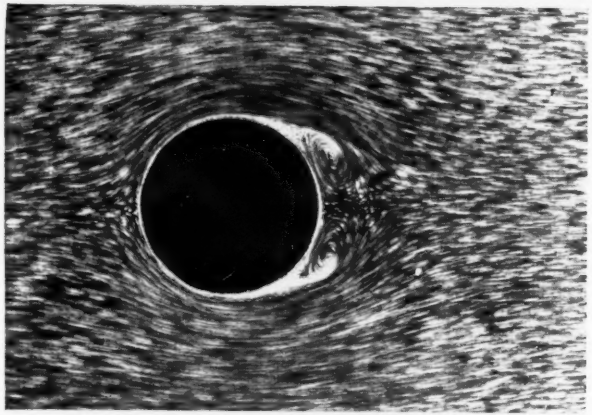


FIG. 25.

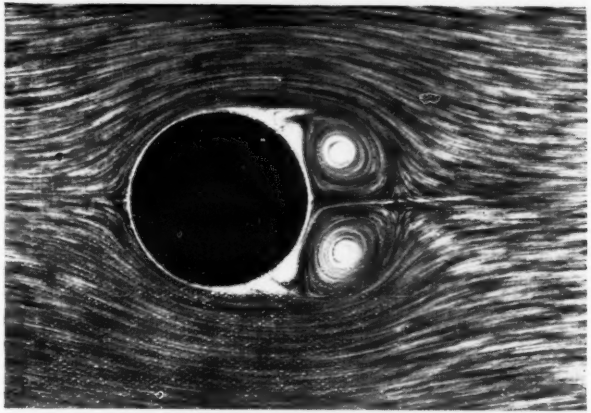


FIG. 26.

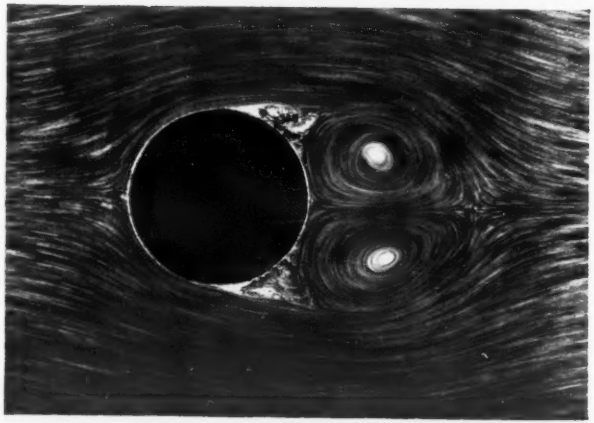


FIG. 27.

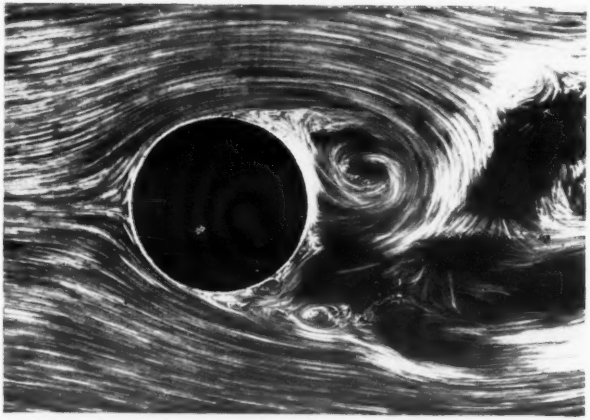


FIG. 28.

FIG. 30.

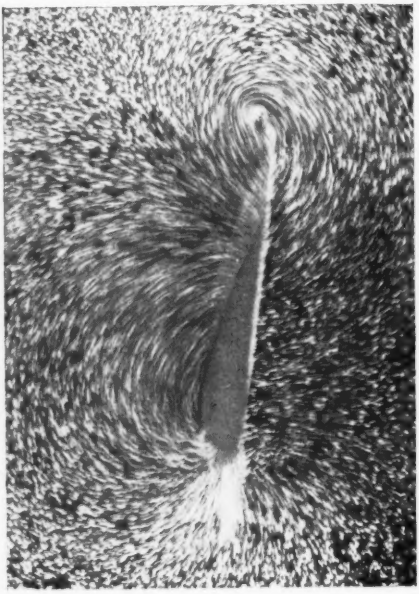


FIG. 32.

FIG. 29.

FIG. 31.

Fig. 32.

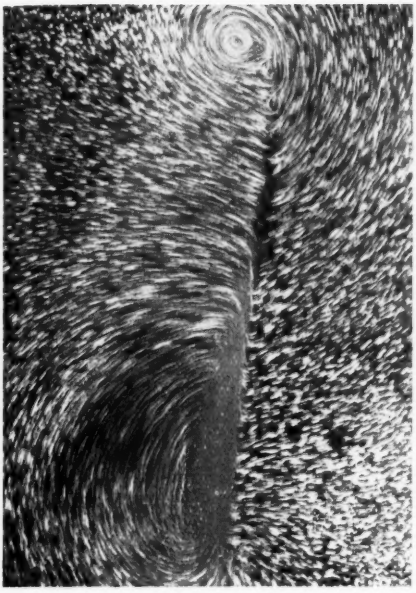


Fig. 33.

Fig. 34.

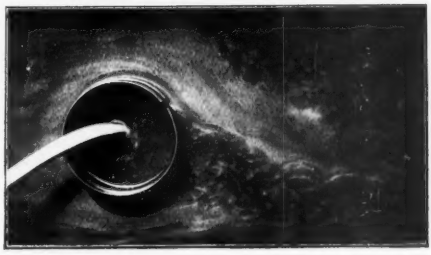


Fig. 35.

Fig. 31.

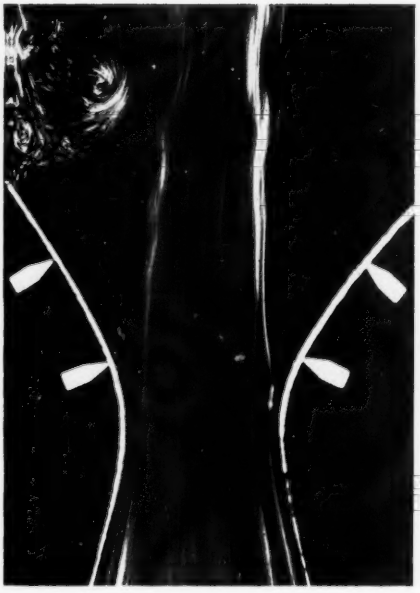


Fig. 36

Fig. 37.

FIG. 39.

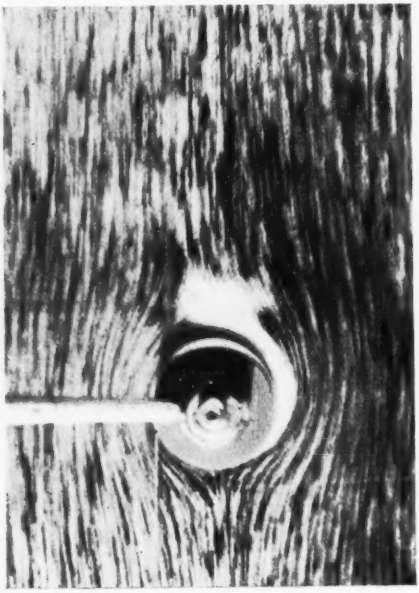


FIG. 42.

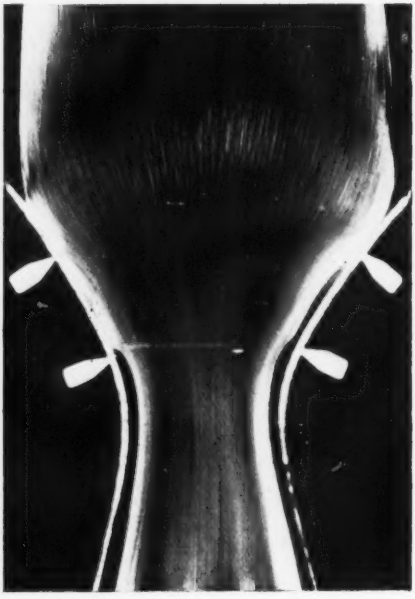


FIG. 38.

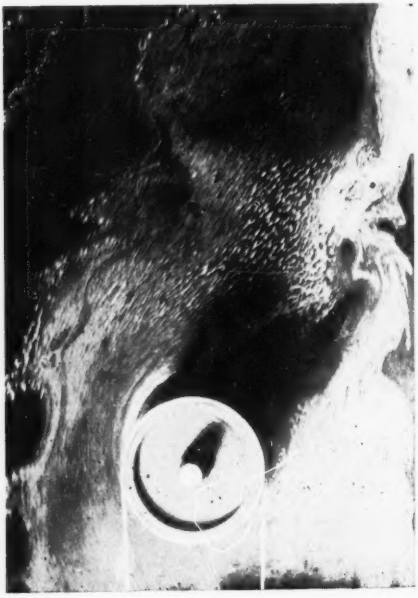


FIG. 40.

FIG. 40.

FIG. 42.

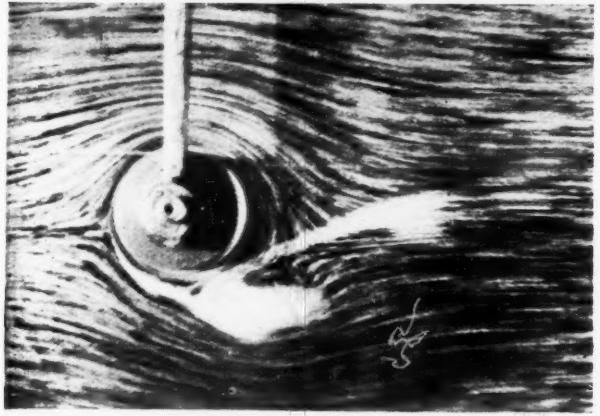


FIG. 43.

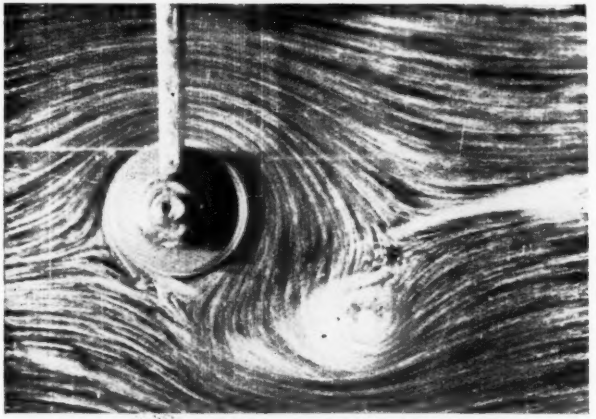


FIG. 44.

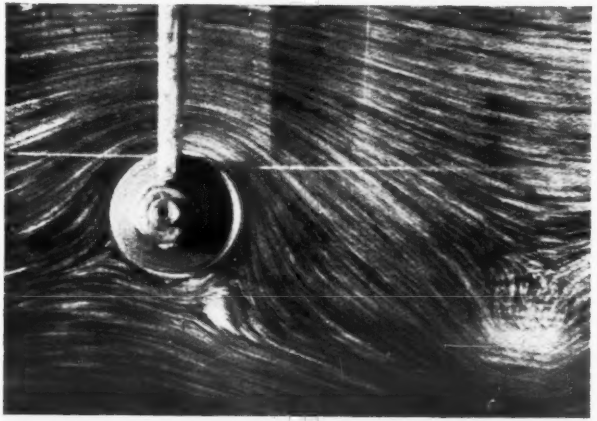


FIG. 45.

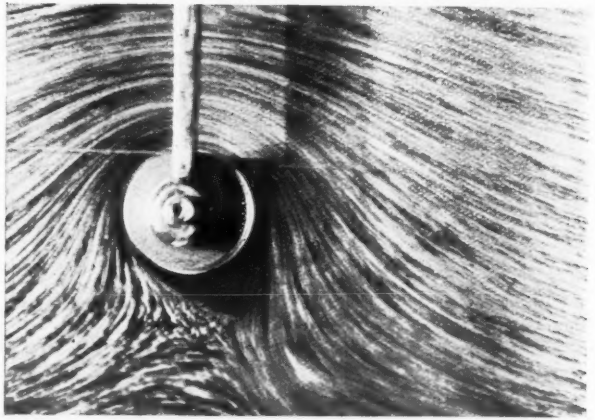


FIG 46.

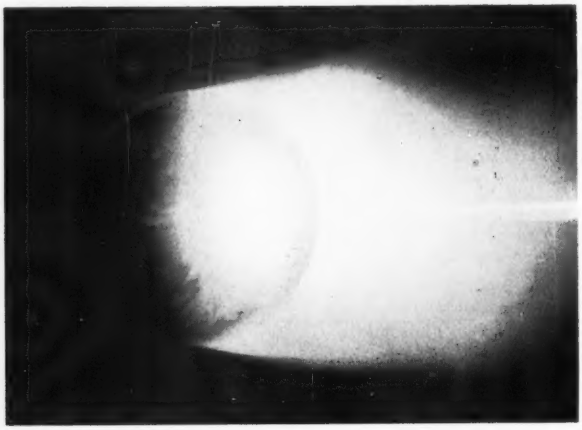


FIG. 47.

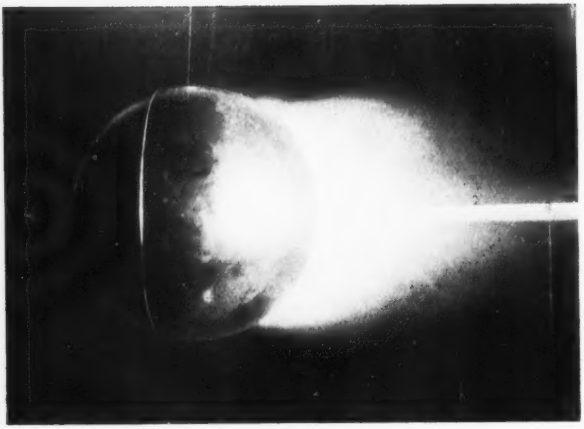


FIG. 48.

probably connected with the fact that the speed distribution in the boundary layer has a point of inflexion behind the point of maximum speed. When the Reynolds' number is sufficiently high, these speed distributions are unstable. However, I am unable to go further into the matter now (see L. Prandtl, *Bemerkungen über die Entstehung der Turbulenz, Physikalische Zeitschrift* (Notes on the development of turbulence), Vol. 23, 1922, page 19).

The technical importance of these turbulent boundary layers lies in the fact that it is precisely those flows in which we are particularly interested, namely, those over aerofoils and propellers, and over airship hulls, which produce turbulent boundary layers. It is due solely to these turbulent boundary layers that in the case of wings and airship hulls the flow follows the boundary practically up to the rear end, and that therefore on the one hand the resistance or drag is very small and on the other hand the ideal flow, which is confluent immediately behind the body, can be used as an approximation to the actual flow. Without this turbulence all these bodies would possess worse properties, greater resistance and less lift. For this reason, when carrying out experiments with models, we must not go below a critical value of Reynolds' scale, otherwise all hydrodynamical similarity with the larger object is lost, a fact well known to experimenters.

We thus get the unique characteristic that it is precisely these turbulent flows of low resistance around bodies which can be so closely represented by the theory of a perfect liquid. This points to the fact that further progress of knowledge in this domain will be made by studying the turbulent movements. We hope that the quantitative deviations of the actual relations from the theory of a perfect fluid which are apparent in the profile resistance and in a diminution of the lift, and also in the separation of the flow from the wing at large incidences will yet be able to be cleared up by the theory of turbulent fluid motion.

There is thus a great deal still to be done in this direction and many difficulties will have to be surmounted before this new goal can be reached. In the meantime we can only proceed slowly step by step. However, the end in view, namely, a profounder knowledge in an important domain, is certainly worth great efforts.

I should now like to show you a short film in which you can see the development in time of the phenomena already familiar to you from the photographs you have seen. The greater part of the film was but recently taken in Göttingen.

The films which I am about to show are arranged so that the camera moves with the object with the exceptions in the latter part of the film. With some of the later exposures at the end of this film the camera is stationary. The surface of the water is strewn with aluminium powder as in the photographs. The first film shows you the configuration of flow round a flat plate, starting from rest and continuing till steady motion is established.

The second and third show the initial motion on a larger scale. The fourth, fifth and sixth sections show you the same phenomena for a circular cylinder, showing first the general flow from a distance and finally two "close-ups." In the latter the formation of secondary vortices can be seen clearly. The seventh section shows a rotating cylinder, it is somewhat ancient and was taken with more primitive means.

The next sections are concerned with lifting wings. No. 8 shows the motion from rest and uniform speed. The vortex sheets are particularly clear. In number 9 the camera is at rest and we can see very well the initial eddy left behind by the wing. No. 10 shows the course of events when the wing has moved a short distance and is again brought to rest. The cyclic motion round

the wing acts as a free vortex and combines with the initial vortex to form a vortex pair which moves off by itself in accordance with Helmholtz's theory.

The last two films, Nos. 11 and 12, show the phenomena in a channel which first narrows and then widens and is fitted with slots. At first the slots are closed and the flow is the usual one. The appearance of a finger marks the opening of the slots on one side, and it is seen how the stream follows this side. In the last section we first see the flow when the slots are in operation on both sides; there is visibly a pure potential flow. At the instant when the finger again appears the slots on one side are closed and the stream departs from this side.

I should like to thank Major Low for very kindly assisting me in the translation and in the reading of my lecture.

My pleasure in doing this is the greater in that I recognise that Major Low has done much to bring the German aeronautical work to your notice.

Sir SEFTON BRANCKER: This most important occasion in our annual programme has always been considered as too serious to admit of immediate and verbal discussion. It is, therefore, my very pleasant task, as President of this Society, to propose a vote of thanks to the distinguished lecturer, Professor Prandtl.

His name has been a byword amongst us for many years—and we esteem it a high honour and a great pleasure that he has been good enough to come and tell us with his own lips the progress of the all-important theoretical work which he initiated.

Science and art have always been the two noblest and two most altruistic of all human activities. Art seems to have arrived at the end of its development —for the great literature, the beautiful pictures and the wonderful music of the past cannot, to-day, be excelled. But in science almost every day we hear of a new step in progress towards wider knowledge and perfection.

If properly handled, aviation will undoubtedly prove to be a great factor in the improvement and furtherance of modern civilisation. Progress in aviation depends very largely on scientific study, research and experiment—and Professor Prandtl stands out as one of the greatest pioneers in aeronautical science—and a pioneer who is still with us, working for the good of the cause. Germany has always been at the forefront in the development of aeronautical science. Close co-operation between that great country and ourselves, in this activity, is most desirable from every point of view. I trust that Professor Prandtl's visit is the forerunner of many other meetings, discussions and collaborations.

Professor Prandtl's name will live for ever, and I call on Dr. Lanchester to support me in thanking him most sincerely for the paper which he has read to-night.

Dr. LANCHESTER: In rising to second the vote of thanks to Professor Prandtl, I must first express my appreciation of the generous words in which he has given recognition to my own contributions to aeronautical science.

Professor Prandtl was a great friend of mine in the early days. We first met in Göttingen at the time when he had just established his wind channel and was endeavouring to obtain uniformity of flow by means of filtering and rectifying devices. Professor Runge, who introduced us, acted as interpreter; Professor Prandtl and I could only smile at one another, for neither could speak the other's language. Professor Prandtl was a great inspiration to several of us who were devoting ourselves to aerodynamics and aeronautical science, and we all looked upon him, even in those days, as a very great authority.

I cannot say that I have myself added anything to the knowledge of aeronautics for many years. I have been otherwise occupied, but I have not lost interest in the subject, and it has given me very great pleasure to listen to Professor Prandtl and to appreciate once more the work he has done and is still doing in the investigation of fluid motion, and to see the advance in photographic technique by which he has been enabled to exhibit to us such beautiful and exact pictures of the flow of fluids recorded by the camera. The reality as revealed is in no way discordant with what we had conceived from theoretical considerations; nevertheless, I do not suppose that any of us could have exactly foretold all that the camera discloses.

When we talk of the progress in science, to which Sir Sefton Brancker has referred, we must not allow ourselves to belittle the arts or the progress in art. The scientific worker is fortunate in being able continually to put the soundness of his work to the test—the acid test of experiment. A large part of his work consists in the discovery and co-ordination of facts. The facts are there, but he does not create them. They are as real as the continent of America discovered by Columbus, but if Columbus had not discovered the continent of America it would undoubtedly have been discovered by somebody else. So with the facts disclosed by scientific investigation, the scientific work of the man who discovers them or the relation between them (which in itself is in the nature of a fact), advances our knowledge sometimes by a few years, sometimes by half a century or more. Even the fruits of the investigations, the discoveries, of Sir Isaac Newton would have been ultimately brought to light if Sir Isaac Newton had never existed; it might have been in 100 years, it might have taken 200 years, we do not know. But the works of the artist are of a different nature; whether it be in literature, music or otherwise, the artist's work is creative. Advance in art cannot be judged by the same standards or measure as we apply to science. It can only be judged by posterity, its fruits and achievements are intangible. Without Shakespeare we might never have had work comparable to his, and without Wagner the "Ring" and his other great works might never have had their parallel in musical history. The advance in song writing made by Hugo Wolf was appreciated by a few only of his contemporaries. We cannot assume, as suggested by Sir Sefton Brancker, that to-day progress in the arts has ceased or a state of stagnation has been reached.

In the public eye the man of science is principally associated with discoveries. These, however, are but the fruits of his work. The work itself partakes of much in common with that of the artist. The individuality of his work lies more in the mental processes involved and methods originated. If we read Newton's "Principia" aright, it is the intuition and breadth of view, the fertility of invention in method, the tireless ingenuity in attack, that hold our attention and give us a picture of the gigantic mental stature of the man. So with others.

In the life work of Professor Prandtl we see at close range the true spirit of the scientific worker, achieving results and bringing to light facts and continuously adapting his methods—sometimes strikingly original—to his purpose, and we know that the name of Prandtl will live.

I have the greatest pleasure in seconding the vote of thanks.

ABSTRACTS AND NOTICES FROM THE SCIENTIFIC AND TECHNICAL PRESS

Issued by the Directorates of Scientific Research and Technical Development

(*Prepared by R.T.P.*)

AIRCRAFT ENGINES, FUELS AND LUBRICANTS

1 Fuels

Cross Cracking Process (Engineering, 1.4.27). (8.512/5676 Great Britain.)

A paper on the Cross cracking process by Mr. F. Heron Rogers is discussed. Referring to the spirit obtained, it is stated that all cracked spirits had a peculiar odour; the Cross cracking process produced a spirit containing 47 per cent. naphthenes; 23 per cent. paraffins; 4.7 per cent. aromatics, and the compression ratio in engines can be raised from 4.5 to 6 without detonation.

2 Lubricants

A Study of Petroleum Lubricants (C. F. Mabery, Ind. & Eng. Chem., Vol. 19, No. 4, Apl., 1927). (8.41/5878 U.S.A.)

Commercial lubricants are defined by initial distillation, proportion distilled below 300°C., specific gravity and viscosity of the distilled products, and stability on a friction testing machine. The heaviest hydrocarbons of refinery distillation are separated and analysed.

Two oils subjected to heavy use, one on a truck and one on an aeroplane, were examined as to specific gravity, viscosity, and behaviour on a frictional bearing. The used oils were found to have undergone little deterioration. Oils with the same viscosity showed wide variations in frictional tests.

A series of medium-grade lubricants, viscosity 320 secs. at 38°C., gave a maximum difference of 12 secs. at 98°C., of 27 secs. at 54.4°C., and corresponding differences in results on the frictional bearing.

Lubrication (W. R. Ormandy, Engineering, 1.4.27, and Engineer, 1.4.27). (8.41/5677 Great Britain.)

These periodicals summarise a paper read by Dr. Ormandy before the Inst. of Mech. Engineers. The paper covered consideration of the uni-molecular nature of surface films, the surface energy of solids, spreading of solid surfaces, viscosity, volatility at flash point, and resistance to oxidisation. Connection between lubrication and "oiliness" is discussed, it being pointed out that no means have yet been devised for the measurement of "oiliness." It is stated that adhesion is probably the basis of the conception of oiliness and assumes enormous importance when the lubricating film thickness falls to an extremely low level. It is stated that the laws governing the frictional resistance in a bearing vary from the laws of solid friction for a very imperfectly lubricated surface, to the laws of viscous liquid flow when the lubrication is abundant.

Engineering states that recent investigations have demonstrated that the property of oiliness is dependent upon a number of variables. According to P. Woog, the dominating factors are:—

(1) Adhesion of the molecules at the inter-face resulting from residual affinity and orientation.
(2) The dimensions and shape of the molecules.
(3) The grouping of the molecules in the surface and adjacent layers.
(4) The molecular rigidity.

Lubricating Oils (Paper by A. G. Marshall & C. H. Barton read before the Inst. of Mech. Eng.; The Engineer, 8.4.27, and Engineering, 8.4.27). (8.41/5704 Great Britain.)

This paper puts forward views which differ considerably from those expressed by Dr. Ormandy in a recent paper before the Institution. The authors deal with "oiliness" as judged by the Deeley machine. The effect of "oiliness" in practice was examined by means of a special positive-testing machine, a single-cylinder engine without valves or sparking plugs with its crank driven by an external motor. The results showed no difference between straight mineral oil and an oil of the same viscosity combined with 10 per cent. or even 20 per cent. of fatty oil. A similar negative result was obtained by measuring the frictional h.p. of actual engines. It was concluded that "oiliness" measurements cannot be relied upon to indicate the general practical value of a lubricating oil.

The second criterion examined was the tendency of an oil to give carbon deposits. The laboratory tests devised to examine this tendency were not found to give any indication of the results to be expected in an engine. The authors examined the viscosity of oils, its variation with temperature, and the effect of such change on the lubrication of engines. It is concluded that the commonly accepted rule "the flatter the viscosity curve, the better the oil," is misleading in connection with questions of power and friction, and is incomplete in connection with the questions of starting effort.

In the discussion which followed, Dr. Ormandy believed that hundreds of examples could be given to show that oiliness did exist and that it was an important property of lubrication oils. He also maintained that the flatter the temperature viscosity curve, the better would be the oil as a lubricant.

Methods of Recovering Crankcase Oil (H. L. Kauffman, Oil and Gas Journal, 10.2.27; abstr. in J. Inst. of Pet. Technol., Vol. 13, No. 61, April, 1927). (8.44/5874 U.S.A.)

This paper contains descriptions of several processes in use for the recovery of crankcase oil. The Alton reclaimer, which is suitable for use on a small scale, subjects the oil to a straining, distilling and filtering process. The light impurities are removed by these means, but the recovered oil is inferior to that reclaimed by a process involving sulphuric acid treatment. The De La Vergne process involves the use of a washing powder with subsequent steaming to remove light fractions. The washing powder tends to emulsify certain types of oil. The apparatus for a similar process, the Miller, is given in detail.

In the General Electric method the oil is first clarified by the use of sodium silicate or a "dope" consisting of a mixture of acid manganese resinate and stearic acid. In order to remove the light fractions the oil is passed in a thin layer over electrically-heated plates. The process is continuous and the plant is designed for small scale work, but several units may easily be joined in order to increase the through-put of oil.

The De Laval process equipment consists of a receiving and treating tank, a centrifugal purifier, a pump for circulating and mixing, and a distilling unit. The oil is treated in the receiving tank with hot sodium phosphate solution.

Apparatus for removing water and breaking emulsions in steamship oils is also described. The process gives oil which may be re-used without further treatment, and the loss of oil during the operation is small.

In another process, after steaming to remove light fractions, all further impurities are removed by centrifuging.

Various facts are also given showing the present disposition of used oils (in America) and an estimation of the quantity of oil wasted yearly.

Critical Speeds Consequent on the Deformation of the Lubricant Layer (C. Hummel, F.V.D.I., No. 278, pp. 48). (8.4/5886 Germany.)

The mathematical theory of lubrication is summarised, the influence of heat being taken into account, by the methods of hydrodynamical theory. A dynamical theory of shaft oscillations in the bearing is then developed. Tests are then carried out in series and critical speeds are determined and shown in graphical charts. The results are interpreted as a graphical relation between a "bearing characteristic function" and the angular velocity, which divides the plane into stable and unstable regions. Two regions of instability are recognised, in the neighbourhood of the second of which the bearings rapidly heat and seize.

3 Dopes and Detonation

Autoxidation and antioxygenic action. Application to the mode of action of anti-detonants (C. Moureu, D. Dufraisse and R. Chaux, Compt. Rend., 1927, 184, 413-417; abstr. in British Chem. Abstr., 15.4.27). (8.514/5881 France.)

Autoxidation, or the union between an oxygen molecule and that of an autoxidisable substance to form a primary peroxide with absorption of energy, has been investigated at 160° for hydrocarbons and animal and vegetable oils. The paraffinic hydrocarbons show an autocatalytic autoxidation preceded by a period of induction which is suppressed by the addition of certain substances. The autoxidations of tetra-hydronaphthalene and of most animal and vegetable oils are higher than those of paraffin, but decahydronaphthalene, naphthalene and copra oil are less oxidisable. The formation of peroxides has been recognised in a number of petroleum fractions. The effects of various amounts of a number of organic compounds on the speed of absorption of oxygen have been noted in each of the above cases. Antidetonants act as antioxygens in the liquid rather than in the gaseous phase of the explosion mixture, and the formation of peroxides precedes all autoxidation. Antidetonants exert their effect by the prevention of the formation of peroxides, but an increase in the concentration of oxygen increases the intensity of peroxidation.

Detonation and Peroxide Formation (Letter from T. Midgley, Jr., Ind. & Eng. Chem., Vol. 19, No. 4, April, 1927). (8.514/5879 U.S.A.)

The letter states that, although the formation of organic peroxides may take place under conditions of low temperature partial oxidation, it is considered most improbable that these peroxides become concentrated in the nuclear drops during compression and ignite them simultaneously when the detonation temperature of the peroxide is reached. It is pointed out that fixed gases knock just as badly as do liquid fuels and there is no reason to believe that there are any liquid droplets in the combustion mixture when fired within the combustion chamber.

Spectography and Internal Combustion Engine (A. Henne and G. L. Clark, Comptes Rendus, 184, 26; abstr. in Eng. Abstr. No. 31, April, 1927). (8.514/5872 France.)

Following Messrs. G. L. Clark and W. C. Thee, the authors, with more perfect apparatus, carried out spectroscopic observations of engine flames. A quartz window and prism were employed. By means of a valve, successive portions of the explosion could be isolated. Running normally, the four quarters of the explosion cycle were about equal in range and intensity, but when detonating the first quarter revealed a more intense spectrum, extending more towards the ultra-violet (2,360 A). Only the lines of water-vapour could be discerned with certainty. The second quarter was feeble, and the third and fourth quarters were as in normal running. Using four different antidetonants, namely, tetra-ethyl lead, iodine, aniline and ethylene, spectra analogous to those of

normal running were obtained. The principal conclusion reached is that with detonation there is a sudden liberation of energy in the first quarter of the explosion, and the function of the antidetonant is to ameliorate the violence of this effect. The fact that, when using tetra-ethyl lead, the lead lines appear only in the first quarter of the explosion leads to the view that these antidetonants, acting as catalysts, are effective chiefly in the initial phase of explosion. The authors observe, however, that no existing theory of antidetonants explains this general behaviour.

Ignition of Substances (A. Egerton and S. F. Gates, J. Inst. of Pet. Technol., Vol. 13, No. 61, April, 1927). (8.514/5863 Great Britain).

The following three articles by the same authors are included in the above journal :—

1. *Effect of metallic vapours on the ignition of substances.*

From this paper it is concluded that :—

(*a*) " Antiknocks," such as lead tetra-ethyl, raise the self-igniting temperature of certain combustible vapours.
(*b*) Lead volatilised or dispersed by means of an arc in nitrogen or argon has a comparable effect.
(*c*) The same method has been applied to test the effect of other metals.
(*d*) The metal atom in incipient oxidation is the seat of the action.
(*e*) The effect on the igniting temperature of various combustible substances has been tested. There appears to be very little effect on the igniting temperature of an alcohol, but a very pronounced effect on that of an aldehyde.
(*f*) The effect of the presence of the metal is to delay oxidation of the combustible substance.
(*g*) The decomposition and oxidation of " anti-knocks " have been investigated, and the existence of a class of volatile intermediate oxidation products has been indicated.

2. *The significance of igniting temperatures.*

(*a*) The ignition point of a substance is defined and its relation to " igniting temperature " discussed.
(*b*) The conditions affecting " igniting temperature " are investigated.
(*c*) Distinction is drawn between the surface reactions and the reactions in the body of the gas. The latter may lead to the establishment of ignition centres, unless dispersed by diffusive influences.
(*d*) The igniting temperatures of various substances are determined; aldehydes are found to ignite at lower temperatures than the corresponding alcohols and hydrocarbons. The effect of mixtures of certain combustible liquids is investigated.
(*e*) The igniting temperature of liquid drops is as a rule lower than that of the corresponding vapour.
(*f*) " Igniting temperatures " are shown to enhance differences in the ignition characteristics of combustible substances and to be related to their knocking characteristics in engines.

3. *Theories of antiknock action.*

(*a*) The main facts regarding antiknocks are summarised.
(*b*) Antiknocks are regarded as negative catalysts which react with and remove those substances which autocatalyse combustion.
(*c*) In the early stages of combustion peroxides are formed which act as autocatalysts. The importance of this in connection with the establishment of ignition centres is discussed.

(*d*) Metallic antiknocks form comparatively stable peroxides which react with and destroy the fuel peroxides and which are then regenerated.
(*e*) The importance of the relative stability of the various peroxides and of concentration of fuel and oxygen is demonstrated.
(*f*) The organic antiknocks are shown to exhibit similar behaviour, but themselves undergo combustion.
(*g*) It is shown how the slowing down of the initial processes of combustion by antiknocks leads to rise in "igniting temperature" and to prevention of "knocking."
(*h*) Other theories of antiknock action are mentioned and briefly discussed.

Pinking in Internal Combustion Engines (G. B. Maxwell, J. Inst. of Pet. Technol., Vol. 13, No. 61, April, 1927). (8.514/5864 Great Britain.)

This article, which is reprinted from "Fuel in Science and Practice," Vol. 6, No. 3, reviews the various theories regarding the cause of pinking; the detonation theory, the flame vibration theory, and the nuclear theory are considered. The various factors connected with engine design, fuel characteristics and inhibiting agents which affect detonation are discussed. It is concluded that further experimental evidence is required on certain points. The spontaneous ignition theory, as modified by Callendar's nuclear hypothesis, seems to fit the facts better than any other suggestion put forward. A more detailed examination of the oxygenated compounds formed during preliminary oxidation of paraffin hydrocarbons is required, since the formation of organic peroxides has not yet been definitely proved. The solution of titanous sulphate used to detect their presence is said by Engler to be a test for hydrogen peroxide, not for organic peroxides. The latter, however, form hydrogen perioxide in the presence of moisture by autoxidation, so that they react to titanous sulphate if not carefully purified. It would appear that the action of "knock inducers" on peroxide formation must also be investigated.

As a preliminary to engine experiments, the mode of combustion of fuel mists in a closed cylinder, at various initial temperatures and pressures, would repay photographic examination. The effect of preliminary "baking," and of a variety of "antiknock" substances and "knock inducers," could in this way be determined.

Antiknock Dopes (Dr. R. A. Weerman, J. Inst. of Pet. Technol., Vol. 13, No. 61, April, 1927). (8.514/5865 Holland.)

This article consists of a statement by the Laboratory of the Bataafsche Petroleum Maatschappij of Amsterdam, describing experiments carried out in 1925. These experiments show that there is a very great difference between the self-ignition temperature of the petrol with and without antiknock dope. A comprehensive list of the self-ignition temperatures of various compounds is given, from which it may be seen that those compounds which have a good antiknock effect also produce very considerable increase in the self-ignition temperature.

Detonation of Gaseous Mixtures of Acetylene and Pentane (A. Egerton and S. F. Gates, Proc. Roy. Soc., A.767, Vol. 114, 1.3.27). (8.514/5689 Great Britain.)

The article describes the experimental methods employed as the conditions for constancy of position of detonation, and the action of antiknocks on the position of detonation.

The conditions for detonation to occur in the same place in a tube of certain dimensions are investigated for acetylene and for pentane mixtures of definite

composition. It is concluded that detonation appears to take place slightly ahead of the combustion front.

The antiknock compounds—lead, tetra-ethyl and diethylselenide—were not found to affect the position of detonation at ordinary initial pressures and temperatures.

Detonation in Gaseous Mixtures at High Initial Pressures and Temperatures (A. Egerton and S. F. Gates, Proc. Roy. Soc., A.767, Vol. 114, 1.3.27). (8.514/5088 Great Britain.)

This paper extends the work referred to in the previous abstract.

Detonation in acetylene and in pentane mixtures at high initial temperatures (230°C.) and pressures (10 atmospheres) has been investigated photographically, using a steel tube fitted with glass windows. Increase of initial pressure engenders earlier detonation up to a certain limit, when further increase makes very little difference.

The effect of increase of initial temperature was also investigated. At a given initial pressure, rise of initial temperature appeared to render detonation slightly later.

Lead tetra-ethyl was not found to affect the position of detonation of the mixtures investigated at high pressure either at normal initial temperature or at 230°C.

Effects of Antiknock Materials on the Spontaneous Ignition Temperatures of Some Inflammable Liquids (Yoshio Tanaka and Yuzaburo, Procs. of Imp. Acad., Japan, 2,221; abstr. in Eng. Abstr., No. 31, April, 1927). (8.514/5871 Japan.)

The authors observed the effects of diethyl selenide, tetra-ethyl lead, aromatic amines and pyridine upon spontaneous ignition temperatures. They found that these appeared to act as catalysts. They suggest that the antidetonating action of lead ethide and other similar compounds cannot be explained by the elevation of the spontaneous ignition temperature.

4 Heavy Oil Engines

Some factors affecting the reproducibility of penetration and the cut-off of oil sprays for fuel injection engines (E. G. Beardsley, N.A.C.A. Report 258). (12.81/5813 U.S.A.)

This investigation was undertaken at the Langley Memorial Aeronautical Laboratory at Langley Field, Virginia, in connection with a general research on fuel-injection engines for aircraft. The purpose of the investigation was to determine the factors controlling reproducibility of spray penetration and secondary discharges after cut-off.

The development of single sprays from automatic injection valves was recorded by means of special high-speed photographic apparatus capable of taking 25 consecutive pictures of the moving spray at a rate of 4,000 per second. The effects of two types of injection valves, injection-valve tubing length, initial pressure in the injection-valve tube, speed of the injection control mechanism, and time of spray cut-off, on the reproducibility of spray penetration, and on secondary discharges, were investigated.

It was found that neither type of injection valve materially affected spray reproducibility. The initial pressure in the injection-valve tube controlled the reproducibility of spray penetrations. An increase in the initial pressure or in the length of the injection-valve tube slightly increased the spray penetration within the limits of this investigation. The speed of the injection control mechanism did not affect the penetration.

Analysis of the results indicates that secondary discharges were caused in this apparatus by pressure waves initiated by the rapid opening of the cut-off valve. The secondary discharges were eliminated in this investigation by increasing the length of the injection-valve tube.

Heavy Oil Engines for Aircraft (R. H. Ward, Aviation, Vol. 22, No. 16, 18.4.27). (12.81/5835 U.S.A.)

This article is an abstract of a paper prepared for the Oil Power National Conference (United States, 18th-23rd April, 1927). Several heavy oil engines are referred to, but all of them have been described elsewhere. The following details are given for the Attendu engine tested by the U.S. Navy Dept. with, it is understood, promising results. The engine was a two-cycle solid-injection two-cylinder model developing 85 b.h.p. at 1620 r.p.m.; better results are stated since to have been obtained; weight per b.h.p. has been reduced to 3.6 lbs. and fuel consumption to 0.5 lb. per b.h.p.

5 Carburation and Ignition

Aeroplane Carburation and Ignition (J. Soc. Autom. Eng., Vol. 20, No. 4, April, 1927). (8.92/5833 U.S.A.)

This article refers to a lecture by L. S. Hobbs and T. Z. Fagan before the Society of Automotive Engineers. The authors deal generally with the trend of aircraft carburettor design and with various types of magnetos for aircraft engines of eight, nine and twelve cylinders, both V type and radial. A new type of spark plug cable now in the service is referred to. This spark plug is encased in a woven covering impregnated with a special preparation which is impervious to water, oil and kerosene, and which, by virtue of its dielectric qualities, materially lessens corona discharge. Wireless interference has been traced to the primary and secondary circuits of the ignition, and to eliminate this interference, spark plug cables are bunched and shielded with thin sheet steel and metallic braid, earthed to the engine at frequent intervals.

6 Test Engines

Variable Compression Engine for the Examination of Liquid Fuels (A. Oberle, Petr. Zeit., Jan. 10th, 1927; abstr. in J. Inst. Pet. Technol., Vol. 13, No. 61, April, 1927). (8.19/5873 Germany.)

A single-cylinder engine is described so arranged that by movement of the cylinder vertically the compression ratio can be varied, while running under full load, between 2 : 1 and 9 : 1, rated at 4 horse-power, 550 r.p.m. The power generated is absorbed in a lamp resistance. The method of examining petrols for their respective points of incipient detonation is outlined. Graphs are given showing the power output with increasing compression ratio when different petrols are used. The power output in each case attains a maximum, and the less easily a petrol detonates, the higher the maximum power output obtainable, other conditions being equal. Several indicator cards of explosions under detonating and non-detonating conditions are illustrated.

7 Heat Transfer

Heat Transfer in Internal Combustion Engines (Dr. Ing. W. Nusselt, F.V.D.I., No. 264, p. 79). (8.57/5890 Germany.)

Gas mixtures were exploded in a steel vessel of spherical internal surface water-cooled externally. The object of the experiment was to separate radiation and conduction taking into account reflection from the walls. Radiation of hot gases is discussed theoretically and applied to analyse the experimental results obtained from a mixture of CO and CO_2, but it is stated that the results are

applicable to other gases on the basis of comparison with the work of other authors.

The results are given in formulæ, tables and graphical representation.

Heat Transfer Alignment Charts (M. Roulleux, Chem. Eng., March, 1927; abstr. in J. Inst. Pet. Technol., Vol. 13, No. 61, April, 1927). (8.57/5889 Great Britain.)

In calculating the heat flow occurring when two liquids are separated by a solid wall it is necessary to know the mean temperature. This may be calculated from the known temperature conditions in the liquids, but the calculation is laborious. The object of the two charts given is to provide a graphical means of obtaining the mean temperature. The second chart may also be used to obtain the area of the heat transfer surface.

Distribution of Temperature and Heat Flow (Dr. Ing. G. Eichelberg, F.V.D.I., No. 263, p. 46). (8.57/5891 Germany.)

I. Prandtl's empirical relation is used in developing expressions for heat exchange between turbulent gas and cylinder wall.

II. Fourier's differential equations of conduction are used to determine the temperature distribution in the cylinder walls.

III. The stresses due to thermal expansion are discussed, for various simple geometrical forms, with methods of reducing the differential equations.

Substantially, the measurements give time average values, but a small variation is shown following the very large variation in gas temperature.

8 *Heat Dissipation by Means of Ribs*

(Prof. Dr. Ing. E. Schmidt, Z.V.D.I., No. 26, 26.6.26, and No. 28, 10.7.26). (8.36/5841 Germany.)

In this article the author has examined by calculation to what extent the capacity of ribs for dissipating heat depends on their shape and dimensions. It is shown that there are certain very definite rib profiles in which the quantity of material used for the ribs is smaller than with any other shape. With ribs on flat surfaces, the optimum profile is bounded by two parabolas with their apices meeting at the outer edge of the ribs. With circular ribs a parabolic curve is obtained. The optimum rib profiles, therefore, are of a shape somewhat resembling a hollow ground razor blade. As this shape is difficult to produce and the sharp edge is undesirable, ribs of uniform thickness and a rib with triangular profile are also examined.

9 *Flow of Exhaust Gases*

Configuration and Resistance of Flow of Exhaust Gases from Valves (Dr. Ing. E. Schrenk, F.V.D.I., No. 272, p. 62). 8.7/5885 Germany.)

A systematic series of experiments with exhaust valves of different sizes, shape and openings are tabulated, and a number of photographs are reproduced showing the actual exhaust flow.

The author does not consider that the body of observed facts is sufficient to establish mathematical expressions for these relations, but it is possible to draw valuable inferences about the design of valves for minimum resistance and back pressure, and by use of a diffuser to reconvert kinetic energy back into pressure head.

10 The Direct Measurement of Engine Power on an Airplane in Flight with a Hub Type Dynamometer

(W. D. Gove and M. W. Green, N.A.C.A. Report No. 252). (8.18/5840 U.S.A.)

This report describes tests made at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics to obtain direct measurements of engine power in flight. Tests were made with a Bendemann hub dynamometer installed on a modified DH-4 airplane, Liberty 12 engine, to determine the suitability of this apparatus.

This dynamometer unit, which was designed specially for use with a Liberty 12 engine, is a special propeller hub in which is incorporated a system of pistons and cylinders interposed between the propeller and the engine crankshaft. The torque and thrust forces are balanced by fluid pressures, which are recorded by instruments in the cockpit.

These tests have shown the suitability of this type of hub dynamometer for measurement of power in flight and for the determination of the torque and power coefficients of the propeller.

AERODYNAMICS AND HYDRODYNAMICS

11 Fluid Motion

The Head Resistance of a Model Rotating in an Air Flow (C. Wieselsberger, Phys. Zeit., No. 2, 15.1.27). (5.32/5665 Japan.)

These tests, carried out in the Aeronautical Institute of Tokio, were made with the object of determining whether the head resistance of a body changes if, in addition to its forward motion, the body simultaneously rotates at a constant angular velocity about an axis of symmetry parallel to its direction of motion. A bullet-shaped body, a cylinder and a circular disc were used in the experiments. The influence of rotation was found to be most marked in the case of a bullet-shaped model, the coefficient of resistance increasing to twice its original value at one speed of revolution. The relation between this increase of resistance and boundary layer phenomena is discussed.

The Laws of Similitude Applied to the Flow of a Viscous Fluid (Engineering, 123, pp. 27-30, 7.1.27; abstr. in Sci. Abstr. B, Vol. 30, 25.3.27. Translation of a paper by Camichel read before the Soc. Franc. de Navigation Aerienne, Toulouse, July, 1925). (5.32/5680 France.)

The main theme of the paper is the use of the principle of dynamical similitude to investigate the flow behind an aeroplane or its portions by experiments on the flow past obstacles in a viscous liquid. The liquid contains suspended particles which are intermittently illuminated, and photographs enable the fluid velocity to be determined in both magnitude and direction. Examples of the photographs are given. By using different fluids the principles of similitude were experimentally verified; the flow round a plate perpendicular to the stream is discussed fully. At relatively great speeds there is a "wake" of "dead water"; at slower speeds the streamlines from the edges unite some distance downstream, the space between being occupied by two vortices; at still lower speeds the flow is laminar. Using different fluids, the speeds at which the flow is geometrically similar were found to agree with the law, and for junction at a specified distance downstream the streamlines were everywhere identical, and the distribution of velocities was that demanded by the laws of similitude.

Aerodynamical Theories Tested by the Principles of Rational Hydromechanics (M. E. Carafoli, L'Aerophile, 1-15.3.27, pp. 71-77). (5.32/5693 Germany.)

A brief synthesis of the work of Magnus, Rayleigh, Joukowsky and Prandtl in setting up a theory of viscous fluid motion round a body or wing. Excellent experimental illustrations of flow round a wing profile are reproduced from photographs obtained at the Institut Aerotechnique of Saint Cyr.

The writer concluded that the striking points of agreement justify the adoption of the theory until something nearer the facts is offered.

Theory of Mutual Influence of Wings and Body (J. Lennertz, Aachen, Z.F.M., 18.1.27, pp. 11-13). (5.32/5783 Germany.)

For mathematical treatment the body is taken as a sphere or an infinite cylinder. In the latter case the trailing eddies have "images" in the body the effects of which on the induced velocities are readily calculated. They produce an increase in the downward flow and in the induced resistance. The distribution of lift for minimum drag is calculated approximately by Fourier expansions and solution of an integral equation. The effect for aspect ratio 10 is sensibly the same as for infinite aspect ratio. Further analysis will be published in a dissertation.

The Problem of Turbulence in Flow between Parallel Walls (H. Lorenz, Phys. Zeit., 1.1.27, pp. 12-16). (5.32/5825 Germany.)

The exact differential equation for laminar motion is replaced by an empirical form for turbulent motion constructed from consideration of superposed cyclic flows, consisting of regular transverse eddies. The redistribution of energy in passing from one type of flow to the other is calculated on the basis of the various assumptions and a value of Reynolds's critical number is obtained. This is compared with Couette's experimental determination of the critical number for rotating cylinders and is found to be 18 per cent. higher. (Note.—The author does not refer to the complication of Couette's experiments by relatively great end effects, and does not refer to G. I. Taylor's complete experimental and mathematical solution of flow between long cylinders. Nor does he note that this type of instability cannot occur in motion between parallel planes.) With a different empirical distribution of velocities he obtains a value in agreement with Heisenberg in a paper read at Innsbruck, 1922. Further, in comparison with his own previous work on flow in tubes he again obtains good agreement with his new result.

Air Flow on Flat Plates (Prandtl and Betz, Ergebn. der Aerodyn. Versuchsanstalt zu Göttingen, 3rd issue, 1927, pp. 1-5). (5.32/5826 Germany.)

Tangential resistance of air flow on flat plates.

The empirical formulæ of Prandtl and von Karman in which the velocity varies as one-seventh power of the distance from the surface is applied to analyse the tangential friction on a flat plate. It is pointed out that near the leading edge there may be laminar flow, while beyond a certain critical point turbulent flow sets in. The resistance is therefore divided into two parts, one part due to the laminar flow near the leading edge and calculated by means of the solution of Blasius for Prandtl's differential equation. The second part of the resistance is calculated by means of the empirical formulæ referred to above. A graphical example is given showing the resistance varying according to the results from laminar flow at low Reynolds's numbers, according to the equation for complete turbulence at high Reynolds's numbers, and according to a composite equation for intermediate values of Reynolds's numbers.

Once the empirical equation for turbulent resistance is accepted, these results give a satisfactory analysis of an observed discontinuity in the resistance

coefficient and of the hitherto obscure result that above the critical value the resistance coefficient approached the straight line corresponding to the one-seventh power only asymptotically.

Cinematograph Examination of Plane Fluid Motion past Obstacles (A. Toussaint and E. Carafoli, Compt. Rend., 183, pp. 48-948, 22.11.26; abstr. in Sci. Abstr. A, Vol. 30, Pt. 4, 25.4.27). (5.32/5845 France.)

At small speeds vortices are formed near the point of division of the central streamline, and these move along the boundary. At greater speeds these disappear, but " dead water " begins to appear, and its boundaries become turbulent at some distance. At higher speeds alternate vortices are thrown off behind, and these enhance the effect of the wake. A stepped profile is found to diminish the effects of the stream disengaging from the boundary, which may explain the reason why stepped wing profiles give greater lift than smooth ones.

Flow and Drag Formulæ for Simple Quadrics (A. F. Zahm, N.A.C.A. Report No. 253). (5.23/5866 U.S.A.)

In this text are given the pressure distribution and resistance found by theory and experiment for simple quadrics fixed in an infinite uniform stream of practically incompressible fluid. The experimental values pertain to air and some liquids, especially water: the theoretical refer sometimes to perfect, again to viscid fluids. For the cases treated the concordance of theory and measurement is so close as to make a résume of results desirable. Incidentally, formulæ for the velocity at all points of the flow field are given, some being new forms for ready use derived in a previous paper. A summary is given. A list of symbols follows the text.

Theory of the Vortex (Joh Dejmek, Phys. Zeit., 1.3.27, pp. 196-198). 5.32/5694 Germany.)

A brief descriptive account is given of the formation of vortices by the rolling up of the boundary layer along the walls of a channel, and is illustrated by three photographs. Reference is made to the meteorological theory of the formation of cyclones at a surface of discontinuity.

12 Pressure Distribution Over Aerofoils

The Air Forces on a Systematic Series of Biplane and Triplane Cellule Models (Max. M. Munk, N.A.C.A. Report No. 256). (5.33/5868 U.S.A.)

The air forces on a systematic series of biplane and triplane cellule models measured in the atmospheric density tunnel of the Langley Memorial Aeronautical Laboratory are the subject of this report. The tests consist in the determination of the lift, drag and moment of each individual airfoil in each cellule, mostly with the same wing section.

The magnitude of the gap and of the stagger is systematically varied, not, however, the decalage, which is zero throughout the tests. Certain check tests with a second wing section make the tests more complete, and the conclusions more convincing.

The results give evidence that the present U.S. Army and Navy specifications for the relative lifts of biplanes are good. They furnish material for improving such specifications for the relative lifts of triplanes. A larger number of factors can now be prescribed to take care of different cases.

Pressure Distribution over a Wing and Tail Rib of a VE-7 and of a TS Airplane in Flight (J. W. Crowley, Jr., N.A.C.A. Report No. 257). (5.336/5869 U.S.A.)

This investigation was made by the National Advisory Committee for Aeronautics at Langley Field to determine the pressure distribution over a rib of the

wing and over a rib of the horizontal tail surface of an airplane in flight, and to obtain information as to the time correlation of the loads occurring on these ribs. Two airplanes, VE-7 and TS, were selected in order to obtain the information for a thin and a thick wing section. In each case the pressure distribution was recorded for the full range of angle of attack in level flight and throughout violent manœuvres. Particular attention was given to the high and low angle of attack conditions. The results show :—(*a*) that the present rib load specifications in use by the U.S. Army Air Corps and the Bureau of Aeronautics, Navy Dept., are in fair agreement with the loads actually occurring in flight, but could be slightly improved; (*b*) that there appears to be no definite sequence in which wing and tail surface ribs reach their respective maximum loads in different manœuvres; (*c*) that in accelerated flight, at air speeds less than or equal to 60 per cent. of the maximum speed, the accelerations measured agree very closely with the theoretically possible maximum accelerations. In manœuvres at higher air speeds the observed accelerations were smaller than those theoretically possible.

Distribution of Pressure over Model of the Upper Wing and Aileron of a Fokker D-VII Airplane (A. J. Fairbanks, N.A.C.A. Report No. 254). 5.31/5706 U.S.A.)

This report describes tests made in the N.A.C.A. atmospheric wind tunnel for the purpose of determining the distribution of pressure over a model of the tapered portion of the upper wind and the aileron of a Fokker D-VII airplane. Normal pressures were measured simultaneously at 74 points distributed over the wing and aileron. Tests were made throughout the useful range of angles of attack with aileron setting ranging from $-20°$ to $+20°$. The results are presented graphically.

It was found that the pressure distribution along the chords is in general similar to that of thick tapered airfoils previously tested. The maximum resultant pressure recorded was five times the dynamic pressure. The distribution of the air load along the span may be assumed to be uniform for design purposes.

Aileron displacements affect the pressures forward to the leading edge of the wing and may increase the air load on the outer portion of the wing by a considerable amount. With the wing at large angles of attack the overhanging portion of the aileron creates usually a burbled flow and therefore a large drag. The balance reduces the control stick forces at small angles of attack for all aileron displacements. At large angles of attack it does this for small displacements only. With the airplane at its maximum speed, an angle of attack of 18°, and a down aileron displacement of 20°, the bending moment tending to break off the overhanging portion of the aileron will be greater than that caused by a uniform static load of 35 lbs. per sq. foot.

13 *Gyroplanes and Rotors*

Autogyro (Flugwoche, 28.3.27, No. 5/6, page 100). (17.3/5832 Germany.)

Referring to the accident to the 300 h.p. Hispano Suiza gyroplane, it is stated that similar constructions are being proceeded with in Germany.

14 *Wall Interference in Closed Type Wind Tunnels*

(G. J. Higgins, N.A.C.A. Tech. Note No. 256). (11.16/5674 U.S.A.)

A series of tests has been conducted by the National Advisory Committee for Aeronautics in the variable density wind tunnel on several airfoils of different sizes and sections to determine the effect of tunnel wall interference and to determine a correction which can be applied to reduce the error caused thereby. The use of several empirical corrections was attempted with little success. The Prandtl theoretical correction gives the best results and its use is recommended for correcting closed wind tunnel results to conditions of free air.

15 Tests on Free Models of New Types

(A. Lippisch, Rhon-Rossittengesellschaft, Z.F.M., 28.12.26, pp. 549-552). (5.323/5789 Germany.)

The principles of dynamical similarity are stated. The dimensions of a model are given with photographs in free flight, and examples of reductions.

16 Performance Tests and Reduction of Data

Performance Calculations of Aeroplanes without use of Polar Diagrams—74th Report of the D.V.L. (Martin Schrenk, Z.F.M., 14.4.27, pp. 158-159). (4.2/5827 Germany.)

An expression is developed for the falling off of engine power with height and the various quantities required are then calculated in terms of coefficients of lift, drag, airscrew efficiency, surface and loads.

A number of abacs (nomograms) are given to lighten the computations.

Cinematograph Records for Measurement of Performance (P. Raethjen, Z.F.M., 28.12.26, pp. 547-549). (4.2/5788 Germany.)

The method has been developed at the Rhon-Rossittengesellschaft e.V., where the investigation of the motions of the centre of gravity and of the motions of axes fixed in the aeroplane about the centre of gravity have been given special attention. Records of aeroplane position are taken through a transparent ruled screen (compare R.T.P. abstract 5.26/5534, Chaps. IV. and VII.) at a ground station, and at the same time records are taken in the aeroplane. Emphasis is laid on devoting extreme care to exact measurement, one complete set of readings accurately made and correctly reduced being worth a hundred doubtful results.

Formulæ for Starting of Landplanes (Hermann Blenk, 59th Report of the Deutsch. Versuchsanstalt fur Luftfahrt, Berlin, Z.F.M., 28.1.27, pp. 25-32). (4.2/5787 Germany.)

The length of starting run and initial rate of climb have limits set by the size of aerodromes and by the surrounding country. The usual methods of performance calculation are arranged in convenient form and graphical results are given of relations between length of run and total weight, surface loading, engine loading, angle of incidence and ground friction.

Aircraft Design and Equipment

17 Structures

Approximations for Column Effect in Airplane Wing Spars (E. P. Warner and Mac Short, N.A.C.A. Report 251). (5.21/5828 U.S.A.)

The significance attaching to "column effect" in airplane wing spars has been increasingly realised with the passage of time, but exact computations of the corrections to bending moment curves resulting from the existence of end loads are frequently omitted because of the additional labour involved in an analysis by rigorously correct methods. The present report, submitted for publication by the National Advisory Committee for Aeronautics, represents an attempt to provide for approximate column effect corrections that can be graphically or otherwise expressed so as to be applied with a minimum of labour. Curves are plotted giving approximate values of the correction factors for single and two bay trusses of varying proportions and with various relationships between axial and lateral loads. It is further shown from an analysis of those curves that rough but useful approximations can be obtained from Perry's formula for corrected bending moment, with the assumed distance between points of inflection arbitrarily modified in accordance with rules given in the report.

The discussion of general rules of variation of bending stress with axial load is accompanied by a study of the best distribution of the points of support along a spar for various conditions of loading.

Limits of Error in Approximate Formula for Resistance to Bending (Researches of the E.V. Fortschrittliche Verkehrstechnik. Otto Steinitz, Z.F.M., 14.2.27, pp. 67-69). (5.1/5785 Germany.)

Approximate methods by planimetry replace tedious calculations of the moments of irregular sections. Eight examples are given.

New Problems in Aeroplane Structure (continued). Lectures at Charlottenburg Technical High School, 1925-1926 (H. Reissner, Z.F.M., 14.4.27, pp. 153-158). (5.21/5846 Germany.)

Single span wings. Torsion of a built-up span. The differential equation is obtained and solved approximately and by the more exact methods of v. Mises, with a numerical example. Ratio of total stresses to pure bending stresses. Ratio of shear stress to pure torsional stresses.

Calculation of Aeroplane Structure with Strut Bracing (Karl Thalau, 71st Report of the Deutsch. Versuchsanstalt fur Luftfahrt E.V. Berlin-Aldershof, Z.F.M., 14.3.27, pp. 105-111). (5.21/5793 Germany.)

In continuation of the 64th Report, improved formulæ are developed for completely triangulated strut frame, *i.e.*, without wire bracing. Three worked-out examples are given. The results are stated to be in good agreement with those in the following abstract.

Calculation of Bracing Struts (Karl Ruhl, 2nd Report of the Design Office of the Albatross Aeroplane Works, Berlin, Z.F.M., 14.3.27, pp. 111-121). (5.21/5794 Germany.)

A more formal discussion of strut bracing. Two very completely worked-out examples are given.

18 Airscrews

Approximate Solution of the Problem of Commercial Airscrew Design (H. B. Helmbold, Z.F.M., 14.1.27, pp. 13-18). (5.41/5791 Germany.)

The circulation round an element is related to the lift and the induced velocities. An application of the calculus of variations gives the best distribution of lift along the blade. Integrations along the blade of four types determine thrust and torque. This applies to a lightly-loaded airscrew with many blades. Prandtl's corrections for a two-bladed airscrew are given in tabular form for the various parameters used. The course of the practical calculation is then summarised.

Micarta Airscrew in U.S.A. (Army & Navy Register, 12.2.27). (5.462/5703 U.S.A.)

The use of Micarta airscrews of the detachable blade type is stated to have been developed to the point at which they are ready for service. It is stated that this material appears preferable to aluminium alloy for horse-powers of about 200.

19 Aircraft Brakes

Sauzedde Brakes for Aircraft (W. Brennan, Aviation, Vol. 22, No. 16, 18.4.27). (5.55/5834 U.S.A.)

This braking device, which is described and illustrated, consists of a triple-laced wire wheel and brake combined. The wheel has three rows of spokes at the hub, laced in a manner which allows all spokes to be equal length, thus reducing the list of replacement parts. By having all of the spokes of equal

length, the inventor claims to have made the strain on each row equal. In lacing the wheel, the spokes are crossed, allowing the brakes to be placed closer to the centre of the hub, thus distributing the braking reaction more uniformly and allowing more efficient streamlining.

20 *The Prevention of Fire in Aircraft*

(Marcel Ducout, L'Aerophile, 1.15.26.) (16.12/5707 France.)

The author enumerates the best methods of preventing fire in aircraft as follows :—

(1) The installation of long piping leading the flame, resulting from back firing, outside the aircraft.

(2) The mounting of the petrol tanks near the undercarriage where they can be easily slipped and are a long way from the engine.

(3) Protection of the exhaust manifolds by concentric fireproof tubes of asbestos and aluminium.

(4) Piping brazed and not tin-soldered, and carefully arranged joints.

(5) Insulation of the electric plant.

(6) Engine with low vibrations.

(7) The mounting of a good automatic extinguisher.

(8) The use of a fuel which is non-inflammable outside the engine.

21 *Design of Seaplane Floats and Flying Boat Hulls*

(H. Herrmann, Jahrbuch der Wissenschaftlichen Gesellschaft fur Luftfahrt, 1926). (5.341/5702 Germany.)

A graphical representation is given of the water resistance at various speeds and with various loadings. A graphical method, developed by Madellung, is given, comparing resistances of various floats and hulls. The relationship between model and full scale experiments is discussed, and a useful table based on dimensional relationships is included in the discussion. The taking-off characteristics are discussed particularly in relation to the size and position of the step. The article concludes with some constructional considerations. Numerous illustrations of English, American and German flying boats and seaplanes are included.

22 *Parachutes*

Veenstra Parachute (La Conquete de l'Air, No. 3, 1.3.27). 16.11/5830 Belgium.)

This parachute has a diameter of 26ft. and weighs 0.13 lb./sq. in. A frame on the principle of a spider's web, actuated by a spring, facilitates the opening of the parachute. The hook is of special design on the snaphook principle with the addition of a ring which, on the shock of opening, slips over the open ends of the hook and locks the hook by screwing on. The parachute is carried in a cylindrical container. The parachute has been successfully tested from 1,000ft.

INSTRUMENTS

23 *Photography*

Distortion of Some Typical Photographic Objectives (A. H. Bennett, J. Opt. Soc. Am., and Rev. Sc. Instr., Vol. 14, No. 3, March, 1927). (14.2/5842 U.S.A.)

In connection with an examination of lenses to be used in airplane topographical mapping, a careful study has been made of the distortion of a large number of high-grade commercial photographic objectives. The apparatus designed for the measurement of distortion for infinite or finite object distance is described. The data show the distortion of the symmetrical anastigmat when the object is at an infinite distance, and also at unit magnification. At unit magnification, with a symmetrical lens, there should be no distortion, but tests of nominally symmetrical anastigmats show sufficient distortion to affect the performance of

the lens. This distortion arises from lack of complete symmetry in the lens construction. Data for the distortion of the unsymmetrical anastigmat (Tessar type) are presented. The results show that rather large variations exist among individual lenses of nominally the same construction. The case in which the axis of the lens is bent, a result of slight prismatic action of the system, is discussed, and a method for determining the magnitude of tilt is described.

The Compensation of Distortion in Objectives for Airplane Photography (I. C. Gardner and A. H. Bennett, Opt. Soc. Am. and Rev. Sci. Inst., Vol. 14, No. 3, March, 1927). (14.2/5843 U.S.A.)

Lenses to be used in taking airplane photographs for topographic surveying must be substantially free from distortion. It is difficult to find objectives satisfactory in this respect and it is shown that in many cases the distortion can be compensated by a plane parallel plate used as an additional component of the lens. The effect of the plane parallel is generally not detrimental to the correction of the other aberrations of the objective. Experimental work is reported which justifies these conclusions.

Spectral Filters (K. S. Gibson, J. Opt. Soc. Am. and Rev. Sc. Inst., 13, pp. 267-280, September, 1926; abstr. in Sc. Abstr. A., Vol. 30, 25.3.27). (14.241/5682 U.S.A.)

This is a compilation, with bibliography, of data relating to filters for the ultra-violet, visible and infra-red regions. As a rule only those filters are considered which have a relatively sharp transition between the regions of free transmission and sharp absorption.

Rectification of Aerial Survey Photographs (M. N. MacLeod, Proc. Opt. Conv., Part II., pp. 653-661, and disc., 662, 1926; abstr. in Sci. Abstr. A, Vol. 30, 25.3.27). (14.31/5683 Great Britain.)

The author discusses the geometrical and mathematical principles underlying a projection method of rectification. It is first necessary to determine the tilt of the camera at the instant when any given photograph was taken, and a simple form of apparatus for doing this is described and illustrated. This apparatus gives the height and tilt, and it is then possible by a simple form of projection apparatus to rectify the photograph. The method is first described with reference to a survey of flat ground, but the application of the method to hilly country is also given, and the use of the " camera plastica " for the determination of ground heights is described.

24 Navigation

Navigation of Aircraft (H. Junkers, English Patent No. 264842). 6.35/5666 Germany.)

For navigating aircraft so as to direct a straight course towards an object on the ground, an apparatus is described in which actual pictures of the compass and of the ground below are produced optically. The observed direction of displacement of the ground is transferred to the compass image, and the aircraft is steered so that this direction coincides with the desired course.

The Mengden Automatic Course Recorder (P. Grenier, L'Aeronautique, No. 92, Jan., 1927). (6.35/5653 France.)

This article describes and explains the method of using M. Mengden's automatic course recorder (auto-estimographe) which constantly indicates to the pilot his position by dead reckoning, and automatically records the aircraft's course on the chart.

25 Measurement of Air Speed

Theory of the Vane Anemometer (E. Ower, Phil. Mag., 2, pp. 881-900, Nov., 1926; abstr. in Sc. Abstr. A, Vol. 30, Pt. 4, 25.4.27). (6.382/5844 Great Britain.)

The writer urges that the vane anemometer, when used to measure speeds for which it has been designed and calibrated, can give very accurate results, and is thoroughly reliable. The calibration curve is sensibly straight, except for small speeds where the friction of the instrument has a marked effect. After obtaining the general equations of motion, the author examines the effects of variations of wind speed and air density. The effect of fluctuations ordinarily met with is less than one per cent.; the effect of air density is much more at low than at high speeds, and should be taken into account in accurate work; the effect of a wind speed varying across the vane circle is shown to be small.

Measurement of Static Pressure (C. J. Fechheimer, Am. Soc. Mech.E.; abstr. in Eng. Abstr., No. 31, April, 1927). (6.38/5882 U.S.A.)

The author describes an instrument for measuring static pressures in air flow determinations. This consists of two concentric tubes, closed at one end; the outer tube is $\frac{1}{4}$in. dia. and the inner tube $\frac{1}{8}$in. dia.; a small cylindrical radial connection is provided between the tubes near the closed end. In a plane at right angles to the axis of the tubes, and at an angle of $78\frac{1}{2}°$ to each other, two small holes are drilled radially, one through the radial connection between the tubes, thus communicating with the interior of the inner tube, and the other through the outer tube only, thus communicating with the annular space between the tubes. At the open end of the inner tube this annular space is closed, and near this end a hole is drilled in the outer tube and a short radial tube is inserted to provide means of connecting the annular space to two manometers, one connected between the annular space and the inner tube, and the other connected to the annular space only. In order to measure the static pressure at any section of an air duct through which air is flowing, the instrument is passed through a small hole in the air duct and is held at right angles to the direction of flow and with the two radial holes towards the impact side. The instrument is then turned slightly on its axis until the reading of the manometer connected between the annular space and the inner tube is zero. In this position the direction of flow bisects the angle between the two radial holes, and the reading of the second manometer gives the static pressure.

26 An Altitude Indicator for Aircraft

(La Nature, No. 2754, 5.2.27.) (6.339/5640 U.S.A. and Germany.)

The U.S. Army Air Corps and the Junkers Company are stated to have evolved independently electric devices for the determination of the height of an aircraft above the ground. Metal plates connected by a wire are mounted on the bottom wing tips. The two plates constitute one plate of a condenser, the other plate being the earth. The air between constitutes the di-electric. The capacity of this condenser is very low and increases as the aircraft approaches the ground. If the condenser is connected in an oscillating circuit, these variations in capacity can be used to produce a signal when the aircraft is within a short distance from the ground, so that the pilot is warned and can take action accordingly.

27 Lighting Equipment

Lighting of Air Routes (General Electric Co. Prelim. Bulletin G.E.A.216). (6.62/5765 U.S.A.)

This bulletin, which is well illustrated, describes the lighting equipment used on the U.S. Air Mail Service. The equipment dealt with includes 24in. Beacon, 4in. × 7in. Beacon, Boundary, Light fittings, Obstruction lights, Field lights, Flood lights and Anchor lights.

28 Flowmeters

Ewing Ball and Tube Flowmeter (J. H. Awbery and E. Griffiths, Procs. Roy. Soc. Edin., Vol. 47, Part I., page 1). (6.51/5894 Great Britain.)

The article describes the principle of the flowmeter and refers to the two most usual modes of motion of the ball; one in which it is quite steady in the tube, and one in which it chatters and vibrates from side to side of the tube. Calibration curves are given for these steady and turbulent motions of the ball in vertical tubes. The effect of inclining the tube is discussed, and curves are given showing the results of experiments with various fluids and spheres in a tube inclined at 45°.

An application of the dimensional theory to this flowmeter is developed.

The Metering of Fluids (H. Moren Brown, Ind. Chem., March, 1927; abstr. in J. Inst. Pet. Technol., Vol. 13, No. 61, April, 1927). (6.51/5888 Great Britain.)

This is a comprehensive survey of the methods available for the measurement of fluid velocity. An electrical method for estimating the flow when an orifice type of flowmeter is used is described. In outline the pressure difference is used to make a mercury column short-circuit a number of resistances which are placed in one arm of a Wheatstone's bridge. The flow may be observed from a galvanometer swing or a recording instrument may be used.

29 Oxygen Apparatus

Explosion of Liquid Oxygen Cylinders (Supplement to the Engineer, 29.4.27). (19.12/5829 Great Britain.)

The article refers to the explosion of an oxygen cylinder described in Le Genie Civil for 5th March, 1927. In discussing the failure, M. Fremont insists on the insufficiency of the ordinary hydraulic pressure test as applied to gas cylinders. In the case of a brittle steel containing numerous inclusions, the hydraulic test would show nothing and would give rise to a false sense of security, while the real danger lies in the development of creeping cracks within the steel.

It is considered that a test for brittleness applied to the steel, and especially a micro-ageing test, would afford a degree of security far greater than that offered by the hydraulic pressure test.

30 Hairsprings

Notes on the Manufacture and Properties of Hairsprings (H. Moore and S. Beckinsale; paper read before the Inst. of Metals and abstr. in Chemical News, 25.3.27). (6.731/5064 Great Britain.)

The function and essential properties of hairsprings and control springs are discussed. The respective merits and disadvantages of steels, ferrous alloys (*e.g.*, Elinvar) and non-ferrous metals and alloys as hairspring materials are indicated. To raise the elastic limit to the required degree, hardening by heat-treatment or by cold-working is necessary, but all hardening operations are liable to produce a state of imperfect elasticity detrimental to the spring. The use of low-temperature heat-treatments to restore elasticity after cold-working (drawing, rolling, and the coiling of the spring) is described. Steel hairsprings are subject to corrosion, but Elinvar is highly resistant. Some details of the manufacture of phosphor-bronze and other hairsprings are given, and the selection of material for hairsprings required to have a low electrical resistance is discussed.

MATERIALS

31 Characteristics of Metals (Ferrous and Non-Ferrous)

Metals for Service at High Temperatures (H. J. French, Chem. and Metal Eng., 33, pp. 591-595, October, 1926; extract of paper read before the Am. Chem. Soc., Washington, October, 1926). (10.17/5681 U.S.A.)

The chemical compositions are given of a large number of alloys which have been found suitable for the most severe service at high temperatures. High tungsten-chromium steels retain a relatively high degree of hardness up to 1400°F. as well as strength, but scale rather heavily. The low carbon, high chromium steels are more resistant to scaling, but soften at the higher temperatures. High chromium steels appear to be suitable for resisting stresses and erosion in steam and gas turbines. Aluminium, although very resistant to hydrogen sulphide at high temperatures, is very soft and can carry but little load at about 480°F. and higher. The nickel-chromium-iron alloys (60 per cent. nickel, 12 per cent. chromium) have been used with success in the production of ammonia. The addition of hardening elements such as carbon or tungsten to these alloys increases their temperature hardness and strength, but also reduces their malleability, so that there are greater possibilities in castings rather than in the wrought metal for the most severe requirements.

Intercrystalline Corrosion of Metals (H. S. Rawdon, Ind. and Eng. Chem., Vol. 19, No. 5). (10.27/5876 U.S.A.)

This article, which is well illustrated, consists of a review of the information available on the intercrystalline corrosion of various metals. When due to corrosion alone, this phenomenon can usually be related to some structural features peculiar to the metal under observation and to its composition. In a few cases, however, such as the corrosion embrittlement of pure lead, a relationship of this kind has not been established, and in the embrittlement of duralumin the evidence is said to be largely indirect.

In general, any practical remedy for the trouble must be along one of two lines. The stress acting on the metal, whether internal or externally applied, may be reduced considerably below the yield point of the metal. Most of the short-time laboratory tests have shown that in order to produce failure within a reasonable time in the laboratory the metal must be stressed close to its yield point. The practical solution of the problem of corrosion cracking in wrought brasses and other copper alloys has been along this line. The other method is to reduce the corrosive attack either by protective coatings, as in the case of duralumin, or by preventing so far as possible the formation and accumulation of the corrosive solution, as in the treatment for the prevention of "caustic embrittlement" of boiler plate. There appears also to be a possible third solution applicable in certain cases, which depends upon a change in the structural conditions in the alloy, particularly as related to the grain boundaries, by suitable heat-treatment or possibly other processes.

Electrolytic Coatings for Aluminium and Light Alloys: their Adhesion and Resistance to Corrosion by Sea Water (J. Cournot and J. Bary, Compt. Rend., No. 19, 8.11.26). (10.27/5849 France.)

The authors have investigated electrolytic deposits of cadmium and cobalt and chromium on aluminium and duralumin after a preliminary coating of copper. The direct coating of aluminium with cadmium was also obtained. The compositions of the electrolytic baths and the conditions of the deposits at the conclusion of the experiments are given.

The degree of corrosion on aluminium and duralumin for various platings are described. In certain instances an interesting hardening of the surface due to the deposit was observed: the factors producing this phenomenon include both the characteristics of electrolysis and the specific hardness of the metal deposit.

Test of Alloy Steels for Strength and Hardness (D. Meyer and M. Sayffert, F.V.D.I., No. 247, pp. 38). (10.12/5884 Germany.)

Sixty-three special steels were supplied covering a large variety of composition and heat treatment. Forty-eight micro-photographs record the grained structure. Ordinary yield tests were made. A method of test of strength under repeated blows and a method of test of hardness by pressing a hard steel sphere into the material are described.

The figures are tabulated to show the relation between the test results. A large number of graphical records show the properties of different steels, the effects of treatment, and the relations between the results of different tests.

Relation between Rockwell and Brinell Numbers (S. N. Petrenke, Bur. St. Tech. Paper, No. 334). (10.11/5696 U.S.A.)

Comparative Rockwell and Brinell tests were made on a great variety of ferrous and non-ferrous metals.

The theoretical relationships between the Brinell and the Rockwell numbers may be expressed by the equations

$$\text{Brinell number} = \text{constant}/130 - \text{Rockwell ball number.}$$
$$\text{Brinell number} = \text{constant}/(100 - \text{Rockwell cone number})^2.$$

The experimental values of Brinell and Rockwell numbers were inserted into these equations and the constants determined. These theoretical equations with the experimentally determined constants may be used to estimate, within an error of plus or minus 10 per cent. the Brinell number from the Rockwell number.

Stainless Steel (Iron Age, Vol. 118, No. 19). (10.12/5667 U.S.A.)

The properties of certain low carbon chromium-iron alloys, commonly known as stainless steels, are discussed. The article describes tests carried out to determine the suitability of these alloys if used in the construction of fuel and oil tanks for aircraft. The article includes a comprehensive table giving the mechanical and corrosion properties of a number of stainless steels.

Magnetic Permeability of Iron and Magnetite in High Frequency Alternating Fields (G. R. Wait, Phys. Rev., Vol. 29, No. 4). (10.16/5697 Great Britain.)

Relative values of the permeability of cast iron filings, iron wires and iron powder in high frequency magnetic fields. Wwedensky and Theodortschik have found the magnetic permeability of iron, steel and nickel in alternating fields to be abnormally large in certain frequency bands (at about 100 metres for iron) and nearly normal in other regions. The general appearance of the phenomenon suggested the existence, in the material, of resonators corresponding to these frequencies. Two experimental methods have been followed in the present investigation, one the resonance method and the other the heterodyne method. Both utilised, in principle, the measurement of the change in inductance of a coil due to the introduction of the sample of material into it. The results are in disagreement with those of Wwedensky and Theodortschik and with those of Kralovec. No anomalous change in permeability was found at any frequency.

32 X-Ray Testing of Metals

Rotation Method of X-Ray Crystallography (J. D. Bernal, Procs. Roy. Soc. 113, pp. 117-160, 1.11.1926—abstr. in Sc. Abstr. A., Vol. 30, Pt. 4, 25.4.27). (10.63/5838 England.)

An important paper giving the first account in English of general methods of interpretation of X-ray, single crystal, rotation photographs. The Ewald

reciprocal lattice and the geometrical law of this lattice corresponding to the Bragg law of X-ray diffraction in crystals are discussed; the interaction of the reciprocal lattice with homogeneous X-rays is analysed; the determination of the size of the true unit cell, and the determination of the indices of the crystal plane from the position of the reflected ray upon the photographic plate or filter are explained; and the requirements of a spectrometer, with which reliable results can be obtained, are stated. A special feature of the paper is the number of transparent charts which very considerably reduce the numerical calculations normally required.

The Application of Rontgen Rays to the Testing of Materials (G. Sachs, Z.V.D.I., 70, 1634-1640, 1926—abstr. in Chem. Abstr., Vol. 21, No. 6, 20.3.27). (10.63/5839 Germany.)

This is a discussion of the principles of X-ray reflection from crystal lattices, and a description of the methods of application of these principles to the examination of metallic substances, either for crystal structure or as a means of determining chemical composition. Characteristic rontgenographs are shown, and several types of apparatus are described and illustrated.

33 *Welding*

Tests in Connection with Gas and Metal Arc-Welding as applied to Aircraft Construction (H. B. Hird, Am. Soc. Nav. Eng.—abstr. in Eng. Abstr., No. 31, April, 1927). (10.18/5867 U.S.A.)

The tests were carried out on plain steel tubes, steel tubes arranged as branches and steel sheets made from mild, chrome-vanadium, nickel and chrome-molybdenum steels. The tubes ranged from $\frac{3}{4}$in. to $1\frac{1}{2}$in. dia. and from 17 to 22 gauge. The heat treatment applied after drawing and before welding is not described. The author states that the thermal effect of gas and metal arc-welding decreases the ultimate strength of all classes of steel by about 20 per cent. for both gas and metal arc-welds. The reduction is about 28 per cent. if the head is ground off, but this may be due to a reduction in cross section during grinding. Unannealed gas and metal arc deposits of weld metal or branches welded to a tube tend to stiffen the tube locally, counteracting to some extent the thermal effect of welding. The thermal effect of an unsymmetrical deposit of weld metal on a tube does not affect the ultimate strength of a tube to a greater extent than a symmetrical deposit. The metal arc-welding of tubes directly to another tube of similar size and gauge is not satisfactory when the branches are subject to a high tensile stress, as the main tube is liable to split at half its ultimate tensile strength. In order to obtain a tee-joint having a high tensile strength at right angles to the tube to which the branch is welded, it is necessary to reinforce the tube with a gusset plate of sheet metal through the tube and extending into the branches. Mild, nickel and chrome-molybdenum steel tubing can be welded satisfactorily by either process if the gauge is not less than 20. Metal arc-welding is as satisfactory as gas welding for aeroplane construction, and has the advantage that warping is much less than with gas welding. Arc-welding machines should have an open circuit voltage of 55 volts, with a current range of 10-18 amp. by increments of 2 amp.

Welding in Aeroplane Construction. A Fundamental Investigation (A. Rechtlich and M. Schrenk, 69th Report of the Deutsch. Versuchsanstalt, Berlin, Z.F.M., 28.1.27, pp. 41-47). (10.22/5786 Germany.)

Distrust of welding in the past was due to lack of uniformity in application. A brief mention is made of hydrogen. The acetylene flame is analysed and the effect of various chemical substances is discussed (C, Si, Mn, P, S, Ni, Al, Cr). In Part II. systematic tests are laid down for laboratory and workshop. Numerous references to other papers are given.

34 Glass

New Resistant Glass (Ind. and Eng. Chem., Vol. 19, No. 5, May, 1927). (10.51/5877 Germany.)

A glass that is said to withstand pressure, heat and acids better than any yet known is being processed successfully in Germany. It was first used for the manufacture of glass tube water gauges and glass bars. The newest tubes produced by this method will sustain a cold water pressure of 20, 45, 65, 80 and 100 atmos.

35 Fabrics

Standard Methods of Applying Fabric to Aerofoils (C. J. Cleary—McCook Field "Slipstream," Ohio, Vol. 8, No. 2). (10.41/5039 U.S.A.)

The article describes and illustrates methods of applying the main fabric, reinforcing tape, lacing cord and surface tape. The general requirements relating to moisture content and the protection of metal parts is discussed.

The Absorption of Water by Cotton Mercerised with and without Tension (A. R. Urquhart, J. Text. Inst., 1927, Vol. 18, No. 2, pp. 155-72—abstr. by L.I.R.A.). (10.41/5855 Great Britain.)

In previous work with loose cotton it was found that the curve showing the relation between the hygroscopicity of mercerised cotton and the concentration of the mercerising solution were of similar form to those representing the swelling of cotton hairs in solutions of sodium hydroxide. This result has been confirmed in the present research on yarns mercerised with and without tension, the differences observed being explainable in terms of the effects of tension. It is also found that the changes in the absorptive capacity of cotton brought about by mercerisation are very similar for all the varieties of cotton examined. The applied tension acts in opposition to the swelling forces, so that the absorptive capacity of cotton mercerised with tension is considerably less than that of cotton mercerised loose. Some figures for technically mercerised materials are given for comparison with those of the laboratory preparations.

Testing of Yarns (American Dye-Stuff Reporter, 1927, 16, 7-14—abstr. by B.C.I.R.A.). (10.41/5708 U.S.A.)

This paper refers to a lecture on the practical application of physical tests to determine the effects of chemical or other treatments on yarns. The measurement of the length of a sample of yarn, the requisite number of tests and the effect of the moisture content of the samples are discussed with reference to actual examples. On the question of strength measurements the author is of the opinion that continuous load extension curves are unnecessary for ordinary comparative results and he himself uses, in conjunction with a Baer single thread tester, sliding wedges of board arranged to arrest the motion of the falling weight at any desired position, extra hooks being applied to take skeins of the full length or such skeins doubled. Elongations are recorded as units of length.

Substitute for Gold Beaters Skin (Aviation, Vol. 22, No. 18, page 928). (12.63/5824 U.S.A.)

A new fabric is said to have been developed which is lighter in weight and of lower permeability than the gold beaters skin fabric. The raw materials are available in unlimited quantities and the cost of manufacture is less than that of gold beaters skin. It is stated that the production of this fabric has passed the laboratory stage and samples have been made successfully on factory scale. The manufacture of full-size experimental gas cell is in progress.

36 Woods

Collected Tests on Timber.—Material Testing Laboratory, Technical High School, Stuttgart (R. Baumann, F.V.D.I., No. 231, pp. 139). (10.31/5883 Germany.)

I. Test methods and appliances for bending, pressure, tension, torsion, impact, hardness. Adhesives and micro-structure.

II. Numerical results for 28 different kinds of timber for selected specimens free from faults are tabulated.

III. Influence of dimensions on results.

IV. Relations between compression, tension, bending and torsional rigidity.

V. Influence of the direction of the grain.

VI. Influence of the condition and treatment of the timber. Difficulties arising from lack of uniformity, variable density. Diseases of timber.

VII. Tests on adhesives.

VIII. Laminated test pieces.

IX. Nomenclature and description.

There are 221 photographs and micro-photographs.

Himalayan Silver Fir and Aeroplane Construction (Nature, Vol. 119, No. 3002, p. 728). (10.31/5823 India.)

The article refers to the Indian Forest Research Institute Bulletin, No. 69, Economic Series No. 26. It is estimated that the existing mixed spruce and silver fir forest could supply a sustained annual yield of more than two million cubic feet; the best localities are enumerated in the bulletin. Investigations were carried out to ascertain the strengths of the two timbers for aeroplane and other construction. Incidentally, it was found that spruce red wood, which is simply the darker, denser material near the central lower portion of the tree trunk, is in no way inferior to spruce white wood, when taken from healthy living trees. Tests have demonstrated that the timber of silver fir is stronger than spruce, and that this is also the case in some parts with the European species of these genera.

Tests have shown that the Himalayan spruce and silver fir are at least as durable as, and stronger than, the corresponding species of Europe and America. Himalayan silver fir has proved to be stronger than Sitka spruce.

37 Rubber

Commercial Possibilities of Rubber Electro-Deposition Process (J. W. Schade, J. Soc. Autom. Eng., Vol. 20, No. 4, April, 1927). (10.52/5837 U.S.A.)

Advantages possessed by anode-deposited rubber are superior ageing properties, reduction in the quantity of material used, applicability to the process of dispersed reclaimed rubber, reduction in size of plant and size and cost of equipment needed, lower labour and power costs, and reduction in waste of material.

The process will be applicable, it is stated, to the various processes of the present rubber factory, such as making continuous rubber sheet, forming continuous tubes in long lengths, impregnating fabric with rubber throughout its structure, part way through, or on one surface only, coating metal with a tightly adhering coat of rubber, forming rubber articles of various shapes with uniform wall thickness or with varied thickness, and making rubber sheets that are thinner than the thinnest that can be calendered.

Electro-Deposition of Rubber (S. F. Sheppard, J. Soc. Autom. Eng., Vol. 20, No. 4, April, 1927). (10.52/5836 U.S.A.)

A brief description is given of the nature of rubber latex together with a review of its physico-chemical properties. The nature of the rubber particles and of rubber after coagulation of the particles is described and the method of rubber plating is explained.

The deposited rubber can be given almost any desired cure by vulcanisation by varying the proportions of sulphur, fillers and accelerators in the mixture. Any stage of softness and elasticity up to that of hard rubber can be secured. Ultra-accelerators may be used which speed up the process at ordinary temperatures to such an extent that they cannot be blended on the rubber rolls.

Any available dyes can be used for colouring the product in the process of deposition, and a grain finish can be given mechanically while the rubber is in a plastic state before it is completely dry, or a natural grain may be left. Ageing properties of the electro-rubber are superior to those of rubber made in the usual way.

ARMAMENT

38 *Guns*

Swedish Aeroplane Machine Gun (Sven. Dag., 23.5.27). (9.14/5859 Sweden.)

Lt. Lars Landin, of the Smaoland Artillery Regiment, and Per Lundgren, Chief of the Jonkoping Fire Brigade, have applied for a patent for a new machine gun which differs from existing types mainly in the mechanical drive which is hydraulic, extremely simple and has a very high degree of precision.

Tests of a model machine gun were recently carried out at Jonkoping and it was found that the precision with which the machine gun fired was the same, whether a single round or a burst of 20 rounds were fired. The machine gun is synchronised for firing through the propeller.

39 *Anti-Aircraft Gunnery*

The Problem of Directing Anti-Aircraft Artillery (Dr. F. Sandkamp, Major a. D., Die Luftwacht, Feb., 1927, pp. 69-79).

The author discusses Oberstleutnant a. D. v. Keller's papers—Artill. Monatsheft, Sept./Oct. and Nov./Dec., 1926, and Luftnachrichtenblatt, No. 10, Oct., 1926. The problem is one of elementary spherical trigonometry when tables of trajectories at all elevations and ranges are available. Von Keller introduces simplifying approximations based on the assumption that the observed angular displacement of the aircraft is less than 10° of the anti-aircraft battery. Three readings must be taken and reduced to gun setting angles, the time being given as 15 secs. down to 10 secs. in favourable cases for loading, sighting and firing. But in 1918 the "Schonian" anti-aircraft director required only $5\frac{1}{2}$ seconds for the cycle. The author admits the value of v. Keller's work, but puts forward the advantages of a sighting circle, replacing the usual bead sight. More accurate methods are to be "mechanised" for rapid reduction to meet the greater heights and higher speeds of aircraft. The probability of a hit is given by v. Keller as proportional to the fifth power of the ratio

$$\text{operating time} \div \text{trajectory time}/\text{operating time} \div \text{trajectory time} - \text{constant}.$$

Anti-Aircraft Progress in U.S.A. during 1926 (Army Ord., Vol. 7, No. 41). (15.21/5814 U.S.A.)

This article is a review of experiments carried out during 1926 with anti-aircraft guns. An anti-aircraft data computer and a stereoscopic height finder are illustrated in the article. The results of tests are given in graphical form.

40 *Probable Errors in Bombing and Anti-Aircraft Fire*

(H. B. Hedrik, Coast Art. J., Vol. 66, No. 4.) (9.33/5875 U.S.A.)

The author assumes the usual form of the probable law, and proceeds to make a mathematical analysis of probable errors of bombing and anti-aircraft fire. Tables are given for various conditions.

41 *Forms and Deformations of Explosion Waves*

(T. Vautier, Compt. Rend., 183, 1335; abstr. in Eng. Abstr., No. 31, April, 1927). (9.61/5870 France.)

The form of explosion waves from the discharge of a pistol in a cylindrical water conduit was investigated by the author's interference method. The wave was reflected backwards and forwards in such a manner that it passed before the interferometer several times. In general the time-pressure curve is broken or discontinuous, rising very suddenly to a peak, at its first few passages before the interferometer. Afterwards, it gradually becomes a smoother curve, with a lower peak and a greater distance from front to peak; also, the velocity of the wave decreases gradually to a limiting and constant value. This is illustrated by the graphs obtained. The distance from front to summit is also plotted against the distance travelled, *i.e.*, against the number of times the wave has passed the interferometer.

42 *The Resistance of Rapidly Moving Bullets in Water*

(Ann. der Phys., Vol. 82, No. 7, page 1014). (9.16/5857 Germany.)

In Annalen der Physik, Vol. 80, pp. 232-244, reference was made to Bauer's experiments on the resistance of rapidly moving bullets in water, and it was stated that the resistance coefficient in water was substantially that which would be given by exterpolation from Prandtl's experiments on the resistance of bullets in air. The journal referred to above now publishes some remarks by the same author in which it is stated that this comparison is not a sound one, unless the forms of flow are substantially the same in the two cases. Reasons why this cannot be legitimately assumed are given.

A CONSIDERATION OF THE DESIGN OF A LIGHT FLYING BOAT

BY JOHN S. L. OSWALD, B.SC., A.F.R.AE.S.

The first point to consider is whether the design should take the form of a monoplane or a biplane. For a reasonably low wing loading and high aspect ratio one immediately finds that the structural weight of the wings alone comes out rather heavy for a monoplane. If to this be added the necessarily relatively high structure weight of the hull and floats, one is led to the conclusion that to keep the weight down so that the machine may come under the term "light," a biplane seems preferable to a monoplane. There is also the point that it is desirable to keep the ailerons well clear of the water. This is easily arranged in the case of a biplane by having the ailerons on the top wing only.

One next considers whether it would be preferable to have a twin-float seaplane or a flying boat design. The flying boat can be moored out in all weathers short of a gale. This is a great advantage from the ordinary user's point of view. The twin-float seaplane does not possess, in one's opinion, this advantage to the same degree.

Assuming the design takes the form of a biplane flying boat, one next considers the power unit, that is to say, whether the latter will consist of a single engine of adequate power or two engines of approximately half adequate power each. With two engines disposed in the wings the manœuvrability on the water is superior to that of one engine with water rudder. In addition there is the fact that although the unit of power is necessary for taking off, once the machine is in the air with two engines, if one engine cuts out one would at least be able to glide at a very fine angle on the other engine.

Assuming that the conclusion has now been reached that the design should be a twin-engined flying boat, a two-seater with, say, two Cherub engines will be considered.

On estimating the weight for this type of design, the weight is found to be of the order of 1,300lbs., the disposition of this being structure 52 per cent., power plant 16 per cent. and load 32 per cent. The load includes pilot, passenger, luggage and fuel for two hours. The petrol tanks, which would be in the top wing, giving a gravity feed, would have a capacity in excess of two hours' flight, so that if the weight of the passenger and luggage was reduced or not carried, then the difference in load could be made up in carrying extra petrol, giving a longer flight range.

If the wings were given a total area of 226 square feet, the aspect ratio being 6, the alighting speed would be of the order of 39½ knots, which is higher than that of existing light aeroplanes, but relatively as safe when the sea is taken as the landing area.

Turning now to the important question of "get off," it is estimated that the water hump resistance is of the order of 220lbs. at 20 knots, the air resistance at this speed 58lbs., giving a total resistance of the order of 278lbs. With fine pitch airscrews the total thrust at 20 knots is of the order of 320lbs. Thus there is a reasonable margin over the total hump resistance.

The gliding angle of the design considered was found to be 1 in 8. This is not so good as that of the modern light aeroplane, but the standard of the latter is unattainable in light flying boat design, owing to the larger frontal area of a hull relative to an aeroplane fuselage.

The maximum level speed was found to be of the order of 67 knots, thus there is a speed range of 39½ knots to 67 knots, or 45½ miles per hour to 77 miles per hour. This would be quite satisfactory as the amateur pilot would have no desire or necessity to fly against 30 miles per hour winds.

The ceiling of the machine was found to be 10,000 feet, which is more than ample for the amateur. The rate of climb at ground level was estimated to be of the order of 369 feet per minute, the times taken to reach 2,000, 4,000 and 6,000 feet being respectively 6, 14 and 25 minutes.

Having now obtained an idea as to the take off and probable performance of a light flying boat, some consideration may be given to the main structural design.

The hull will first be considered as it is the most important feature of a flying boat. The latter spends more time on the water than in the air. Personally, one would build the hull of duralumin rather than of wood. It has been demonstrated that if anything, a hull built of duralumin can be made as light, if not lighter, than one of wood. In ship practice it has been found that wood is the most suitable material up to a certain tonnage, but it is submitted that this is due to the comparison being with steel, not with duralumin. The production man-hours would also be in favour of the duralumin hull. The question of the corrosion of the duralumin may now be ignored provided the duralumin is properly anodically or otherwise treated. There is no "soakage" with a duralumin hull, which is a distinct advantage where the reserve of power is small.

For the main plane superstructure and tail unit one would at the present stage stick to standard practice, namely, wooden spars and tubular struts.

The above has been submitted in the hope that any discussion which may follow will help to stir up some interest in this side of light plane work. If we consider our magnificent coast line and rivers which involve practically no aerodrome expenses we, as a nation, are missing a great deal of flying experience, sport and fun by leaving the light flying boat undeveloped.

REVIEW

The Conquest of the Air

By C. L. M. Brown. (Oxford University Press, The World's Manual, 2s. 6d.)

This is one of those volumes of "history without tears" for which, with all respect to the august source from which it emanates, it is difficult to see the justification. But if such books are to appear is it too much to expect that care should be taken over their compilation and that they should not, as in this case, be simply "scissors and paste" compositions culled from previous publications without any attempt being made to correct mistakes which may have crept into the originals? In different places Mr. Brown acknowledges his indebtedness to three books: Sir Walter Raleigh's "War in the Air," Mr. Hodgson's "History of Aeronautics in Great Britain" and Mr. Vivian's "History of Aeronautics." From internal evidence it appears that a perusal of these volumes is Mr. Brown's sole claim to consideration as an authority on aeronautical history. At any rate it is abundantly clear that he has not been to the sources from which they gained their knowledge. Mr. Hodgson is the most careful and accurate historian aeronautics has known, but even he can on occasions nod. An example of this occurred when, in a moment of temporary aberration, he stated in his book that Chard, where Henson and Stringfellow worked, is in Gloucestershire. Faithfully Mr. Brown perpetuates the mistake.

At one point we at first thought Mr. Brown was for once being original, when, in his summary of the Dædalian legend, he makes the surprising statement: "Later Icarus stole the wings and launched himself into the air"—an undeserved slur on the boy's honesty which is certainly not attributable to Ovid. But a little research revealed the fact that a careless piece of writing on Mr. Vivian's part supplies the authority from which Mr. Brown derives his gloss on the original legend. His faith in Mr. Vivian's accuracy is indeed touching.

Referring to Veranzio's XVIth century drawing of a parachute he writes: "By means of this parachute he (Veranzio) made safe descents from the tops of buildings." Since Mr. Hodgson's comment in this connection—which is unquestionably correct—is that "there is no reason to believe that Veranzio . . . himself tested the efficiency of this invention," we turned again to Mr. Vivian's book for enlightenment, to be rewarded by finding the following passage: "It is to be conjectured that he soon got tired of dropping from high roofs"—which was, of course, quite enough for Mr. Brown.

Columns of the Journal could be filled with similar examples of Mr. Brown's methods of making the history which he is not content merely to record, but the pursuit would be as wearisome as it would be fruitless. The sad part of it is not only that the Oxford Press, who published both Sir Walter Raleigh's and Mr. Hodgson's books, should have been persuaded to put their imprimature on this effusion, but that Mr. Brown is, we understand, one of the Air Ministry officials who are charged with the education of aircraft apprentices at Halton.

W. L. M.

BRANCH NOTICES

Leeds Branch

Chairman.—Professor W. T. David.
Committee.—Mr. R. Blackburn, Mr. J. Gilchrist, Mr. F. G. Wayman.
Hon. Secretary.—Mr. T. M. Naylor.

The opening meeting of the above branch of the Royal Aeronautical Society will take place in October, 1927, at Leeds University, when Air Vice-Marshal Sir Sefton Brancker, President of the Royal Aeronautical Society, will give an address. *The exact date will be announced later.*

The Committee hope that a full attendance will be made for this opening meeting and also wish it to be known that the meeting is open to visitors.

The Chairman has been notified that members of the Leeds Branch, who are students of any university or college, may become members of the Yorkshire Aeroplane Club, Ltd., at a very reduced fee of 10s. 6d. Student members wishing to join this club should write to the Secretary, Mr. J. F. Barnes, 39, Swan Arcade, Bradford, when they will receive full particulars of their meetings and the arrangements made for flying.

Yeovil Branch

Paper read before the above Branch at Yeovil on the 17th February, 1927.

AIRSHIPS

BY H. B. WYN EVANS, ESQ. (R.A.E.).

History

Not to go too far back in years, and to relate a few facts within the lifetime of most of you present to-night, I may commence by saying that it was in 1909 that Admiral Lord Fisher instructed Admiral Bacon to proceed with the design and construction of a rigid airship, attention having been called to the success attending Count Zeppelin's efforts and to the fact that we could not realise the dangers to which we might be exposed until we possessed airships of our own.

Admiral Bacon got into touch with Messrs. Vickers' experts, and Naval Airship No. 1, nicknamed the "Mayfly," was built at Barrow. Messrs. Vickers deserve all credit for their pioneer work on airship design and construction in this country, and it was only very bad luck that prevented their building the bigger ships. The Government could not spare the steel to complete the big shed at Flookburgh, near Barrow, and Messrs. Vickers were compelled to carry on with relatively smaller "rigids," including R.26 and R.80, whilst Messrs. Armstrong, Messrs. Beardmore and Messrs. Short Bros., with their new large sheds, were able to build the larger ships.

During trials at Barrow in September, 1911, the "Mayfly" was wrecked. In attempting to lighten her structure the keel was weakened and she broke her back.

However, Admiral Murray Sueter, who was superintending the construction of the "Mayfly," pressed the Admiralty not to give in but to carry on, profiting by errors discovered. The Board of Admiralty, however, decided against them and so all airship work in this country was suspended. Admiral Sueter toured Germany, Austria and France and reported on the airship progress and persuaded

the Admiralty to order a Parseval from Germany in 1912, and in 1913 got them to approve the building of another rigid by Messrs. Vickers, this time of the Zeppelin type, and so R.9 was commenced, the construction of which I had the honour of superintending on behalf of the Director of Naval Construction.

Actual construction was not seriously commenced until 1914, and on the outbreak of war it was again suspended, but when Lord Fisher took the helm in 1915 new heart was put into the airship enthusiasts, and work went on as fast as was then possible. The R.23 class followed rapidly, of which four ships were actually built and were successful. The R.23X class, of which R.27 and R.29 were completed, was due to the late Mr. Campbell himself, and was a great courageous step, omitting the heavy, strong, tubular keel and so designing the hull that it could itself take all the stresses.

Then followed the famous R.33 class, of which R.34 did the double crossing of the Atlantic in 1919 and R.33 her recent involuntary flight over the North Sea. This class was based on contemporary German design, details of which were gleaned from the Zeppelins which were brought down in this country and in France.

At the time the R.33 class were building at Messrs. Armstrong's and Messrs. Beardmore's, Messrs. Short's, at Bedford, were proceeding with the wooden ships, R.31 and R.32. These were built on the Schutte-Lanz principle. Then followed R.36, an improved R.33, subsequently converted into a passenger ship, and R.37, the former at Beardmore's, the latter at Cardington, where she remained until last year, when she was broken up to make room for the new 5,000,000 cub. ft. ship R.101.

I may add here that on Lord Fisher's taking the reins of office at the Admiralty in 1915 between 40 and 50 of those wonderful little "blimps" were ordered. These little ships and their slightly larger brethren the North Seas and Coastals did over 2,000,000 miles patrolling during the war, and were—as evidenced by the German authorities themselves—the dread of their submarine commanders.

The development of airships in this country was again suspended after the tragic loss of R.38 in 1921.

R.38 was built to outfly the German both in speed and height and consequently had to be designed to smaller factors of safety. For commercial purposes we do not need to design to such fine limits. Great altitudes of the order of 25,000 to 30,000 feet are not necessary, as in war time; 5,000 to 10,000 feet with economic speed is required, combined with a sufficiently robust construction to withstand all weathers and lie to a mast indefinitely. As regards mast mooring, I shall have more to say later on.

Before proceeding to a consideration of types a short digression regarding hydrogen might be of interest.

Hydrogen

Hydrogen is the gas invariably used at present. Helium is the only other gas that can be considered and of course has the tremendous advantage of being non-inflammable. It cannot yet, however, be obtained in sufficient volume. The United States use some for their ships as they have a very valuable plant erected at Fort Worth, in Texas, for the extraction of helium from the natural gas.

For comparison from a lift or buoyancy point of view let us consider the gross lift of a ship of the size of R.36. Filled with hydrogen she will have a gross lift of 64 tons against 59 tons if filled with helium. Thus one would have to pay for non-inflammability with the loss of 5 tons lift—a serious loss of nearly 8 per cent.

Hydrogen is manufactured at our airship stations by two main processes, the silicol process and the iron contact process.

The silicol process consists in bringing caustic soda into contact with silicon. In the actual manufacture a high grade ferro-silicon is used which contains round about 90 per cent. of silicon, and the pure silicon and pure caustic soda contents are worked in the proportion of roughly 10 : 17. The gas produced by this process is singularly pure, generally containing 99.9 per cent. pure hydrogen, and about 20 cubic feet are obtained for every pound of commercial ferro-silicon used.

With reference to the iron contact process, there are many varieties of plant, but in general the process consists in passing steam over heated de-oxidised spathic iron ore which produces hydrogen. The iron is a catalytic agent and can be used over and over again. In actual practice the steam is not passed directly over the hot metallic iron, but the iron ore is reduced by means of water gas to pure iron. By this means a spongy coating of metallic iron is obtained on the refractory iron oxide, thus affording a freer passage for the steam and the water gas. This water gas is produced by passing steam over red-hot coke, the coke being subjected to an air blast for one minute to bring it up to a state of incandescence, after which the blast is shut off. The steam is then turned on for about four minutes and the water gas produced passed straight to gasholders. Before it is injected into the retorts containing the iron it is purified to remove the sulphuretted hydrogen, carbonic acid and other impurities.

Thus there are two principal stages in this process; first, the reducing of the iron ore, and secondly, the oxidising of it which produces hydrogen.

For every ton of iron ore used, about 600 cubic feet of hydrogen can be generated per hour.

Whilst referring to hydrogen it will be relevant to consider briefly the problems of lift. These are identical with the problems of buoyancy in the case of water and primary considerations of the behaviour of gas can best be followed by inverting those of water. For instance, hydrogen flowing upwards to fill a gas container is analogous to water being poured into a fabric bag, viewed upside down.

As in the case of an object floating in water, the weight of the airship, its structure parts and loads must, when in static equilibrium, equal the weight of air displaced. The major part of this displacement is of course that due to the gas containers.

The "lift" of an airship at any moment is therefore primarily dependent on the volume and characteristics of the gas contained in her gas containers and the density, pressure, temperature and humidity of the surrounding air.

The density of air decreases with height above sea level. Details of this variation are given in tables and need not be elaborated here. This decrease in density calls for a corresponding increase in the volume of gas in the gas containers. Provided no change is made in the loading of the ship, the nett lift of the ship throughout these variations remains the same. It is only when there is no further room for the further expansion of the gas that conditions of "lift" alter. If the airship is forced above such a height, the gas inside the containers increases in pressure and ultimately escapes through valves, set to blow at a predetermined pressure. The gas escapes cannot be replaced. Consequently, on the ascending force being removed the ship returns with a less nett lift than before.

So much for the practical side of the considerations of "lift." It will take too long to enter here into the theoretical details of meteorological questions affecting the surrounding atmosphere and also of superheating which deals with the differences in temperature between the gas inside and the air outside the gas containers, which naturally seriously affects the "lift" and which is due *inter alia* to the direct impinging of the sun's rays on the envelope. For these details I cannot do better than to refer you to Major Scott's lecture before the Royal Aeronautical Society and recorded in their journal of March, 1924.

Types

Airships are naturally divided into three main classes:—

(1) *The Non-Rigid*, in which the envelope maintains its shape solely by reason of the internal pressure of gas.

(2) *The Semi-Rigid*, in which, as in the non-rigid, the envelope maintains its shape by an internal pressure, in excess of the surrounding atmospheric pressure, but in which the greater part of the bending and longitudinal stresses introduced by the rigging is taken by a rigid keel.

(3) *The Rigid*, which comprises a so-called rigid structure of girders and wires covered by an outer fabric and containing a number of individual gas-bags.

Now to consider the classes separately:—

The Non-Rigid

The smaller airship—with volumes say up to 350,000 cu. ft.—must of necessity be non-rigid as the gross lift does not allow of a rigid framework or keel.

The non-rigid was in use before the war and a considerable amount of experimenting was carried out at Farnborough with the early army airships—the Beta, Gamma, etc., and later at Kingsnorth with the S.S.'s (or "Blimps" as they were then christened), the Coastals and the North Seas.

The non-rigids can be sub-divided. In fact there are three main types:—

(*a*) The plain circular section envelope from which the car, etc., is suspended from patches on the envelope, of which the S.S. and S.S.Z. are examples.

(*b*) Where the plain circular section envelope is reinforced by "trajectory" bands passing from a band or girdle round the base of the envelope over the top. The car, etc., is suspended from this girdle. The German "Parseval" is an example of this type—in fact, the trajectory band system was introduced by Major Parseval.

(*c*) The Astra Torres class following the designs of Signor Torres, in which the section of the envelope is a trefoil, *i.e.*, the envelope is trilobular with the rigging inside attached to the cusps of the intersecting lobes.

In both (*b*) and (*c*), *i.e.*, the Parseval and Astra Torres, the overall height is considerably reduced as they enable the car to be carried nearer the underside of the envelope.

In (*c*) the radius of the curvature at any point of the section of the envelope is lessened and hence for any pressure the fabric tension is correspondingly reduced.

In this country we have experimented with and during the war used all types, and the Astra Torres type as evidenced in our "Coastals" was particularly successful.

The design of the envelope or gas container of a non-rigid airship introduces problems of great interest. One has primarily to consider efficiency of shape with restricted overall height, with the effect of control surfaces relative to the line of thrust so far below the centre of the envelope. The rigging supporting the car cannot be allowed to be too flat—otherwise it introduces serious compressive forces in the envelope which can only be resisted by high internal pressure, followed by increased fabric tensions and consequently stronger and heavier fabric.

As you are aware, a large number of S.S.'s or "Blimps" were required hurriedly at the beginning of 1915 for anti-submarine protection and it was essential for production purposes to aim at extreme simplicity. Hence for the

first few dozen ordinary aeroplane fuselages were employed, but later cars—more suitable for extended patrol work—were designed and fitted. Towards the end of the war twin-engine cars carrying a crew of five were designed and a few built. Altogether 150 S.S.'s were built during the war.

Meanwhile, commencing in 1915, the larger Coastals were in preparation. These ships had a greater speed and radius of action. Actually 45 of these were built during the war, and the later ones had an endurance of about 12 hours at 50 knots.

The larger type still—designated the "North Sea" class and destined for work with the fleet—had an endurance of 24 hours at 50 knots. Of these 16 were built.

To quote some actual records, the longest flight by a North Sea ship was 101 hours, and that for an S.S. 51 hours. In the latter case the crew of three were continuously on duty. Coastal No. 9 at her patrol station in Cornwall was inflated on July 1st, 1916, and deflated September 14th, 1918. During this period of 805 days she flew 2,500 hours or an average of over three hours per day throughout. These facts speak for the reliability and durability of these crafts.

It should be remarked that a considerable number of British non-rigids were built and supplied to the French, Italian, Russian and American services.

Now let us consider the general details of these non-rigids. Firstly the

S.S.—These little ships were 143 ft. long, about 30 ft. diameter, and had a cubic capacity of 60,000 or 70,000 cub. ft. Their gross lift was approximately two tons of which 30 per cent. was disposable.

The single engine type generally carried a Rolls "Hawk" engine of 70/80 h.p. and had a maximum speed of a little over 40 knots.

Actually, I believe, the prototype of the 70,000 cub. ft. "S.S. Zero" blimp was built at the R.N. Airship Station at Capel in June, 1916. The tare weight—to use a Civil Airworthiness Committee term—was 3,150 lb. and its gross lift with 95 per cent. pure gas was 4,500 lb.

The envelope, which can be taken as typical of the S.S. class generally, was made of C.C. biassed fabric. This means that the fabric was two-ply with one ply laid at 45° to the other; the diagonal one is generally outside. The weight of each layer of "C" fabric was 80 grams per sq. metre and between the plies a layer of rubber was introduced weighing 75 grams per sq. metre. The inner or gas face of the fabric was proofed with 20 grams of rubber. The total weight, therefore, of the fabric was 255 grams per sq. metre and on top of this the outside dope with an aluminium content must be added.

To allow for the expansion and contraction of the gas under varying conditions of pressure and temperature, so as to retain the distended shape of the envelope, it is necessary to have an internal air container, into which air is forced as the gas pressure tends to decrease. This is generally termed a "ballonet." In the above S.S. there were two such ballonets, each having approximately 10,000 cub. ft. capacity.

These ballonets are filled, one forward and one aft. They were constructed of D.D. biassed fabric. There was a layer of rubber between the plies, and the gas face was proofed with rubber so that the total weight was 240 grams per sq. metre plus, of course, the dope. These ballonets are stuck on the inside of the envelope.

The ballonets are filled by air forced through fabric valves in a trunk communicating with an aluminium blower pipe placed in the slipstream from the airscrew.

The trunk is of C.C. biassed fabric similar to the envelope. The blower pipe is hinged to that it can be raised flush with the envelope when not in use. The valves are known as "crab pots" and are arranged to allow the air to

pass either into the forward or aft ballonet separately or to stop the air supply entirely. These valves are operated from the car.

Each ballonet is also fitted with a non-return valve to prevent the air forced through the "crab pot" from escaping.

The envelope itself is fitted with a rip panel for purposes similar to those in an ordinary balloon. It is positioned well forward on the top.

The usual types of manœuvring and automatic gas valves are carried on the envelope, the former on top, the latter, usually three in number, underneath.

The bow is stiffened by radiating stiffeners of H section silver spruce bent to the curvature of the bow. They are 26 in number and are secured to the envelope by three lacing patches each.

The manœuvring of these airships is controlled by elevators and rudders. In this particular case of the S.S.Z. instanced above, there are two horizontal stabilising planes each having 110 sq. ft. The hinged flaps on each have an additional area of 34 sq. ft. each. The single rudder plane has a superficial area of 185 sq. ft.

They are all constructed of spruce spars and ribs, aluminium tube boundaries, steel bracing wire and are covered with linen fabric doped with six coats of ordinary dope and four of aluminium.

The rigging, by means of which the car is suspended from the envelope, consists of a number of cables each terminating in bridles, which in turn are secured to the envelope by means of Eta patches.

The disposition of the rigging and the corresponding Eta patches is found by design and also in some cases by a water model. As mentioned previously, by filling a fabric model with water and inverting it, the exact case of the airship filled with hydrogen is simulated.

Coastals

To pass on to the larger type of non-rigid of 170,000-200,000 cub. ft., let us confine our attention to the larger of these designated the "C" star. This ship was 220 ft. long and 44 ft. diameter. Its gross lift was 6½ tons, of which, as in the S.S., approximately 30 per cent. was disposable lift.

It carried two engines—one a 150 h.p. Renault or Sunbeam—forward of the car and the other a 260 h.p. Fiat aft. Its maximum speed was 51 knots.

The tare weight was only a little short of 10,000 lb.

As described above, the Coastals were built to Torres designs, being trilobular. The section amidships was to all intents and purposes an equilateral triangle, apex downwards, on each side of which a semi-circle is described. The car suspensions were tangential to the two lower lobes and direct to the apex of the triangle.

The envelope fabric of the "C Star" ship comprised B.B. doubled material with 100 grams of rubber between the plies and 10 grams on the gas surface for the top lobe and C.C. biassed fabric for the lower lobes.

The ballonets in this ship numbered six, three on each side. Each of the forward ones were of 8,600 cub. ft. capacity. The midship ones were each 17,200 cub. ft. and the after ones 8,600 cub. ft., giving a total ballonet capacity of 68,800 cub. ft., or approximately one third the total volume of the envelope. This corresponds to an attainable height of nearly 10,000 ft.

The curtains forming the sides of the above mentioned equilateral triangle were of "R" grade linen of 120 grams per square metre. These curtains are not gas tight.

The blower system for maintaining air pressure in the ballonets is similar to that in the S.S.'s. The blower tube faces the after airscrew and the air is led along a fabric trunk on the underside of the envelope, and so to each ballonet as required. The "crab pots" and non-return valves are fitted as in

the S.S. type. Mechanical blowers are carried in the cars in case of a defect in the above system.

The bow stiffeners are again of H-section spruce and are usually 32 in number, bent to the shape of the bow and secured to the envelope by channel patches—four to each stiffener.

The rigging is fitted on exactly the same principle as in the S.S. ships.

Gun Tube and Platform.—On most Coastals a gun platform was fitted on top of the envelope. Access to this platform was obtained by means of a tube passing right through the envelope. It consisted of a fabric shaft about 30in. in diameter, maintained circular in section by ash hoops. About 30 of these hoops were employed more closely spaced towards the top owing to the greater pressure.

Fins, Rudders and Elevators.—In the "C Star" ship, each horizontal fin and the vertical fin had an area of 287 sq. ft. and each elevator flap and the rudder flap an area of 67 sq. ft.

Semi-Rigids

The Italian designers have all along seemed to favour the semi-rigid type of ship and have produced several very successful designs. As mentioned above, this type comprises an envelope whose form, like the non-rigid, is maintained by internal pressure, combined with some form of rigid keel from which the loads are suspended. They depend for their strength to resist static and aerodynamic forces partly on the envelope and partly on the keel. This keel relieves the envelope of certain stresses to which the non-rigid is subjected, and hence permits of lower gas pressures with a corresponding reduction in the necessary strength and weight of the envelope fabric. This saving of fabric weight has been proved to more than offset the weight of the keel. Semi-rigid airships have been constructed up to over 1,000,000 cub. ft., the two largest being the P.L.26 and P.L.27, built by Germany, which were 1,120,000 cub. ft. These two ships embodied many interesting features, including spherical partitions which divided the envelope into sections so that the accumulation of pressure at the upper end of the ship when pitched was avoided.

Semi-rigids can be sub-divided into three distinct types:—

(*a*) In which the car is suspended from a rigid frame which is fitted close up under the envelope and faired in with it. The French "Lebaudy," the German "Veeh" and Siemens-Schückert were examples of this type.

(*b*) In which a rigid keel is constructed sufficiently long to spread the load over the whole length of the envelope. It is directly attached to and enclosed by the envelope, and contains the machinery and control compartments. The weight of this girder keel is distributed by internal rigging. The envelope surrounds a gas container of similar shape. The intervening space contains air, the pressure of which is maintained by a supply forced through a non-return valve in the nose, by the forward motion of the ship. The gas container is divided into several compartments to prevent complete collapse if punctured, to check surging and to obviate the accumulation of pressure at the upper end when the ship is pitched.

Examples of this type were the Italian "Forlanini" and "Verducio" of which the most recent ships have been the "Roma" and the American R.S.1. The gas container of the Forlanini ships was divided into 12 compartments.

(*c*) In which the keel, instead of being rigid, is made "articulated." The Italian military "M" and "P" classes are designed on this principle. The longitudinal compression members of the keel are

attached directly to the underside of the envelope, are pin-joined in two directions, and connected transversely by horizontal struts. The whole is wire braced to get lateral stability, but is capable of bending in a vertical plane. The car is suspended from this keel by an ingenious triangulated system of rigging which lends itself to quick dismantling when the envelope becomes deflated and adjusts itself to the shape of the envelope during inflation, thus allowing the latter to assume its natural form without local strains.

In these ships as in the " Forlanini " type the gas container is divided into several compartments by transverse fabric bulkheads. In the " M " class there are six such compartments.

Rigids

As previously remarked, of the various types of construction the non-rigid arrangement is sufficiently satisfactory for small ships, because the envelope is amply capable of providing sufficient rigidity with reasonably small internal pressure. For the larger ships it is necessary for the gas container to be divided into a number of compartments for reasons I have already given.

Further, the diameter of the envelope cannot increase in size indefinitely with increase in volume owing to the corresponding increase in circumferential tension, and hence attention was directed towards meeting these difficulties by the construction of a rigid framework enclosing a number of separate gas containers. Count Zeppelin's work in this direction is a praiseworthy record of perseverance and was only made possible by political influence and by continued financial assistance. In such a design there is no need for an excess internal pressure to maintain shape and the fabric of the gas containers can therefore be exceedingly light.

The framework takes all the shearing and bending stresses, and is covered with a tightly stretched doped fabric which offers a smooth plane surface to the air and encloses between itself and the gas containers a layer of air which is useful in insulating the gas from too sudden changes of temperature due to outside influences.

The possible variations in rigid design fall, I think, under four heads in order of importance:—

(1) The keel-less type.
(2) The strong backbone or keel type.
(3) The vertical, girder type.
(4) The axial type.

I will refer to these in their inverse order because it is to the first two types that modern rigids belong.

The fourth type, which I have designated " axial," has for its main strength member a single longitudinal boom at the axis of the ship, around which circular transverse frames are located by radial wiring. The peripheries of these frames are held in position by longitudinal wires, outside which is fitted a fabric outer cover. The control and power units are suspended directly from the axial boom as also is the longitudinal corridor running fore and aft along the underside. This corridor carries the fuel and ballast containers and crew spaces. This type has not been actually constructed and from investigation appears to involve a heavier tare weight than the other three.

The third type introduces an extension of the strong keel of Type 1 in that the backbone consists of a framework the full depth of the ship and consequently takes the shape of the full profile of the ship. This doubles the number of gas-bags, since they must be of a semi-circular section and lie on either side of this framework. No ship of this type has so far been built. From investigation it also appears to involve heavier structural weights than the first two types.

The early Zeppelins and the early British, including the "Mayfly," R.9 and the R.23 class belong to Type 2. In each of these ships the backbone consisted of a strong keel of steel and duralumin tubes lying outside the main hull structure and strong enough in itself to resist all shearing and bending stresses. All assistance obtained from the main framework was "thrown in" and as a matter of fact very materially increased the factor of safety. This accounted for the immense strength of these ships. The structural weight was consequently prohibitive as very little disposable lift was available.

The purest example of Type 1, *i.e.*, the keel-less type, in which category all recent and modern rigids fall, was the R.23X class, designed by the late Mr. Campbell, the Head of Airship Design under the Admiralty until his tragic death in R.38 disaster. In this design the whole strength was developed in the hull framework. It was a courageous step and bore out fully the designer's hopes. Two ships of this class were actually built—R.27 at Inchinan and R.29 at Barlow. Both ships were deleted and broken up.

The R.33 and subsequent classes of British ships and all the Zeppelins after the first few experimental type belong to this group.

Admittedly, they differ slightly from R.23X class in that there is a strong rigid keel in the form of a corridor running practically the whole length of the ship. This keel, however, is not as in Type 2, designed to take all the bending and shearing forces on the structure, but assists in distributing the loads over the length of the hull and prevents concentration of weights. Most of these ships were built of duralumin girders with solid drawn high tensile steel wire.

Reference should be made here to the "Schüttelanz" airships constructed entirely of wood. In general design they were similar to the Zeppelins and we built two of them, R.31 and R.32. It is generally accepted, I believe, that the successive improvements in the Zeppelins were largely influenced by the Schüttelanz designs. Certainly the latter were the first in the field with those details which aimed at and obtained higher speed and better manœuvrability, viz., separate streamlined power units and monoplane tail fins. Our two ships were considerably faster than the contemporary Zeppelin type.

It was, I believe, the combination of Schüttelanz and Zeppelin efforts that produced the L.30, which marked such an advance on previous ships. Of this class L.33 was brought down in this country in 1916 in a sufficiently undamaged condition to provide the data from which our R.33 class was evolved.

German design advanced with great rapidity during the war, especially in the direction of higher speed and increased disposable lift, giving them greater manœuvrability, endurance and altitude—the latter of great value against heavier-than-air attack during bombing raids.

Although we had only completed our R.33 and R.34 towards the end of 1918, the Germans had at least two of the L.70 class flying. L.70 herself was destroyed on her first flight to England with many valuable experts on board. These ships were nearly 2½ million cub. ft. against R.33's 2 million, but had 64 per cent. disposable lift against R.33's 45 per cent., and had a maximum speed of 66½ knots against R.33's 52. The differences therefore were very great.

After the armistice one of these super ships, L.71, was flown to England and housed at Pulham, and the remaining one, L.72, to France. The former was deleted and broken up without being flown again, but the latter, renamed the "Dixmude" by the French, was lost in the Mediterranean with all its crew.

Mention should here be made of the two smaller but very highly efficient ships, the "Bodensee" and the "Nordstern," completed at Friedrichshafen after the war. They were designed for commercial purposes and the "Bodensee" actually carried out 103 trips and carried 2,450 passengers. They were later handed over to France and Italy. Since this the Germans have built a large passenger ship for the United States. This ship, the Z.R.3, christened "Los Angeles," was successfully flown across the Atlantic by Dr. Eckener and a

German crew. The time occupied from the mouth of the Gironde to Sandy Hook was 70 hours. It had a capacity of 70,000 cub. ft., *i.e.*, 2½ million cub. ft. corresponding to 76 tons gross lift. Her L/D ratio was 7.3 and she had no parallel body. Her speed was 70 knots and she had a disposable lift of 56 per cent. against the 64 per cent. of the L.70 class. The difference is accounted for in the extra structural weight involved in the passenger accommodation and other requirements.

Modern Developments

We in this country have now embarked on an even greater problem—the design and construction of two rigid airships of double the capacity of the largest built to date. It is ambitious, but I can personally vouch for the vast amount of research and the great caution with which the problems involved have been and are being tackled by the design staffs at Cardington and Howden. To enter into any details here would be impossible from a point of view of time alone. As I suggested in my opening remarks you must persuade one of the Cardington staff to come down and speak to you about this ship alone. It will well repay you. Colonel Richmond has described the research side very fully in his paper recorded in the R.Ae.S.'s journal of October last year.

I have endeavoured to touch very briefly on the general history and present position of rigids. As these will, in my opinion, be the principal type of airship in use in the future, it will be of interest perhaps to run through the main characteristics of their construction, and for this I will take the R.33 class as typical. The future larger ships will, I think, only vary in detail.

The three main items in a rigid airship are:—

1. The hull structure.
2. The fabric details and
3. The power units.

The Hull Structure

The hull structure consists essentially of a series of longitudinal girders connected by transverse rings, the whole rigidly braced with steel wiring. The form of the hull structure takes that which combines least resistance with reasonable practical manufacture. As instanced above, the length to diameter ratio has decreased in the more recent designs, *i.e.*, they are getting relatively fatter.

The material used for the girders has so far been either wood or duralumin. The Schütte-Lanz Co., of Germany, put all their faith in wood, and were thereby handicapped in production. We built two Schütte-Lanz ships, of which R.31 began to fall to pieces very rapidly, due to inferior adhesive in the plywood, but R.32 fared very much better and was used throughout in the training of the American crews preparatory to their taking over the ill-fated R.38.

The material used so far by Germany and ourselves is called duralumin, an aluminium alloy, with which you are all very well acquainted. It is manufactured by Messrs. Vickers, at Birmingham, and its composition is approximately:

Aluminium		94—94½%
Copper		4— 4½%
Magnesium ... ... .65	... ...	1¼—2%
Manganese ... ... .50		
Silicon ... ... .50		
Iron ... ... .30		

Its specific gravity is 2.79 and its ultimate tensile strength is 25 tons per square inch with an elongation of 18-20 per cent. in 2 ins.

Its properties, however, depend very materially on its heat treatment. It can reach 35 tons per square inch with a low elongation. Its annealing and

various heat treatments in the ingot state are usually carried out in muffle furnaces, but in the workshops where it is being fashioned into various airship details "salt baths" are used.

These baths consist of iron troughs, heated by gas or oil, and contain a mixture in equal parts of potassium and sodium nitrates. For the annealing the temperature of the bath must be maintained at 350°C., and the material after immersion must, if thin, have all the work that is done upon it completed within an hour or so, because the material gets harder as time elapses.

After all the necessary work has been done on the item it is immersed in a bath, the temperature of which is 490°C. and immediately quenched in water. This is called the final heat treatment and allows the material to return to its full strength.

The very narrow limits of temperature between which the baths must be maintained for the developing of the full strength in the material, and the consequent delicacy in working generally, necessitate very great care and attention being paid at all steps of the manufacture of details, the girders and the assembly of the structure.

The actual manufacture of a girder to ensure there being no twist in its length is a very interesting process and one which caused a great deal of trouble in the initial stages, but which has now been entirely overcome and which can be carried out by two girls after only a few days' instruction.

The wiring consists of high tensile steel wire of 90-100 tons per square inch and is used to brace the main transverse polygonal frames and also to brace the panels formed by the longitudinal and transverse girders on the outer surface of the hull structure. There are two distinct systems of diagonal panel bracing, called the major and minor diagonal systems, which serve to resist the shear and torsional forces to which the structure is subjected.

The major system in effect connects up the main joints and the minor system bracing individual panels.

Erection

The method usually employed up to the present in erecting the structure is first of all to build the transverse rings. The individual girders forming the sides of the polygon are laid on a skeleton table and jointed together while lying flat on this table. Of course, spiling marks are scribed from the point marking the axis of the ship.

The radial and other bracing wires are then inserted and tensioned up, the tension employed usually being 150-200 lb., according to the gauge of wire.

The ring thus formed and rigid in its own plane is connected from each joint to the ends of an axle by rope, thus presenting the appearance of a Rudge-Whitworth wheel. The ends of the axle are then slung by tackle from the overhead runways and the ring up-ended and dropped into its corresponding cradle.

When two or three of these rings are in position the longitudinal girders are fitted and then the diagonal wiring inserted and tensioned up.

The Fins

Are generally built up on the floor of the shed just below the stern of the ship, and are then lifted into place and rigidly connected.

In the early Zeppelins and in our R.9 to R.33 classes the fins were of the single plane type, but in the latest ships have been made of a varying triangular section, the outer edge being as formerly a single girder, but the trace of the fin body with the hull taking a streamline form. This streamline form appreciably reduces the resistance as well as reducing the number of interbracing and stay wires.

The Rudders and Elevators

At the after end of the stabilising, fins in the early Zeppelins and our R.9 were of the box or multicellular form, but in later ships are of the balanced type and are controlled by wires fitted to sectors, and passed round sheaves and fairleads running right along the keel to the control pedestals in the control car forward.

The Keel

Or corridor was in the early ships external and built up of steel and duralumin tubes with flexible joints, but rigidly braced with steel wire.

In R.33 and later classes the internal keel was employed in which the various petrol tanks and water ballast bags were suspended. This keel forms the corridor from end to end of the ship, giving access to the various power units and to the mooring platform forward and the gun position in the extreme point of the tail.

The Fabric

Outer Cover.—To house the girder structure and provide a smooth streamline form the hull is covered by a fabric sheet.

In the earlier ships this cover comprised panels made of linen stretching from the topmost girder down to the keel on either side between two adjacent transverse rings, but in later ships the panels have been longitudinal, sometimes up to 100 ft. in length, and stretched between two adjacent main longitudinal girders. This latter method is found very much more efficient than the old system, as it enables a very much tighter cover to be provided which reduces resistance, prevents flapping, and hence gives longer life to the fabric.

The later covers also have been made of cotton fabric instead of linen and weigh approximately 110 grammes per square metre.

The cotton fabric is first coated with a pigmented nitro-cellulose or acetyl dope, depending on its position in the ship. The final coats of dope with an aluminium content are applied at the same time as the fabric is being stretched in position on the ship, that is, the final doping and hand tautening are carried out concurrently.

The aluminium content is principally to prevent superheating and also to check the effect of the ultra-violet rays on the rubber and cotton of the gas-bags. It is not generally realised what a very big difference the sun makes in the lift of a ship of these dimensions. The effect of the sun passing behind a cloud and re-appearing again was distinctly felt until steps were taken to obviate the effect of superheating. During summer months as much as 20°F. of superheating has been experienced even with modern outer covers, and this on a ship of 2½ million cubic feet means an increase in buoyancy of 2½ tons and a consequent possible loss of gas. Considerable improvement has, however, been made recently and the maximum temperature difference is now of the order of 3° or 4°.

Over the lacing "sealing strips" are stuck, thus rendering the outer cover a complete sheath to the ship.

The completed outer cover fabric weighs 160 to 180 grammes per square metre.

Gas-bags

We now come to the business portion of the airship, the gas-bag or gas container.

A rigid airship contains a number of individual gas-bags which, when inflated, fill the space between the consecutive main transverse frames, and thus take the form of a cylinder whose diameter is that of the ship.

In R.33, where the spacing between the main frames is 10 metres, there were 19 of these gas containers. In R.38, a ship nearly half as large again, we had only 14, because in this ship the spacing was increased to 15 metres. In R.101 the main transverse frames are to be more closely spaced amidships than at bow and stern, so that the volumes of the individual gas-bags will be more nearly equal than in all previous ships.

The main problem in these gas-bags is to obtain a light and strong fabric which, with a rubber and goldbeaters' skin or other facing, is sufficiently gas-tight. The modern gas-bag, as manufactured in this country until recently, was made of very fine cotton, the inner face of which was proofed with a thin layer on which was stuck a single or double layer of goldbeaters' skins. A thin layer of varnish was applied to this skin lining; the layer of skins forms, therefore, the gas face of the fabric.

The bare cotton fabric itself was specified to weigh 65 grammes square metre, and the rubber proofing 20 grammes square metre, and pigmented for reasons referred to above. The completed fabric weighs about 130 to 140 grammes square metre and is very impermeable to the diffusion of hydrogen. A wash of solution was spread just prior to laying the skins, and the resulting gas-bag fabric weighed 160 to 170 grammes square metre.

The area of the transverse end of a gas-bag in the parallel portion of a ship of R.33 class is about 4,800 sq. ft. If we take a pressure of 5 mm. of water at the bottom, the average pressure over the end is about 18 mm. of water, which corresponds to a total end pressure of nearly 8 tons.

The difference in methods of manufacture between Germany and ourselves was that the German authorities made up their sheet of skins independently of the fabric, and stuck this sheet on to the fabric by means of a special adhesive. In this country we have up to the present placed the skin separately on the prepared rubber-proofed surface of the fabric—a wash of naphtha over the rubber proofing providing sufficiently good adhesion. At Cardington, however, since the recommencement of airship activities in 1925, we have successfully developed the German method.

The goldbeaters' skin which is used is the membranous covering of the cæcum of the ox and it varies in size from about 24 to 40 inches long and 6 to 10 inches wide. The skins are stored and packed for transit in barrels of salt crystals, and before use have to be thoroughly washed and scraped free from most of the adherent lumps of fat. They are then soaked in a 5 per cent. solution of glycerine in water. The skin absorbs the glycerine to a noticeable extent and thus retains its flexibility. The upper portions of a gas-bag, where the gas pressure is greatest, were double-skinned, and the permeability of this double-skinned fabric was below .5 of a litre per square metre per 24 hours.

Permeability is an extremely complicated problem. Goldbeaters' skin has a very low permeability to hydrogen—about 200th of its permeability to water vapour. It has practically no permeability to petrol; these facts are difficult to explain.

Owing to the fact that only one skin is obtainable from each beast, and that the number of skins required for a ship of 2¼ million cub. ft. is about 500,000, it will be seen that if airships are to come into fashion it would be wise to look for a substitute, and this is being done. It will be interesting to note in this connection that the Germans attempted a substitute by growing the skins by means of bacteria, and also produced a kind of glue so good that when the war ended they were making a fabric which consisted of cotton and glue alone without skins.

The complete gas-bag fabric so made possesses no great resistance to

bursting as is the case with the envelopes of non-rigid and semi-rigid airships and must, therefore, be supported by a net.

In our ships up to and including the R.33 class and in all German ships there were two sets provided, one of wire of a mesh of about 24 inches and inside this one of ramie cord of about 12in. mesh. The wire net was more or less continuous, the wire set up loosely running at 45° to the longitudinals and lightly connected thereto. The cord net was made in panels and connected to the respective longitudinal girders.

In the later ships a new system was introduced. Cord nets were omitted and in place of the wire network a system of circumferential wires was fitted. These wires were continuous round the ship in planes about 9in. apart parallel to the transverse frames and passed through eyeletted holes in the longitudinal girders. At those parts of the ship where the differences in tension between adjacent sides of a longitudinal tend to be greatest, that is, in way of the C, D and E longitudinals, these wires are made fast to so-called "catenary" wires, which are rigidly connected to the adjacent main joints, thus relieving the longitudinals of any local lateral loading that would otherwise exist.

The percentage fullness of each gas-bag is continually varying, due to changes in temperature and pressure of the surrounding atmosphere occasioned by the ship changing her altitude during flight, or by variations in the heat received direct from the sun, or reflected from the earth, or water, or whatever the nature of the ground may be.

It will be readily seen that some arrangement is necessary for providing a means of automatically relieving the pressure of the gas inside a gas-bag to prevent bursting. This is done by fitting at the bottom of each gas-bag one or more automatic valves which will "blow" at a pre-arranged pressure. In R.33 this pressure ranged from 16 mm. of water at the after end to 9 mm. amidships and 13 mm. forward. This variation allows for the different heights of the various valves above a common level when the ship is on an "even keel," and also for about 10° inclination either way. The gas exhausting through these valves escapes up a trunk between adjacent gas-bag and out through hoods fitted at the top of the ship. These trunks are formed of wooden hoops about 30in. in diameter, kept in position by fabric tapes. The gas-bags themselves form the covering as they naturally envelope these rings when they are inflated.

The gas volume and pressure in a gas-bag is also controlled by a manœuvring valve fitted in the top of each bag and operated from the control car. By means of these valves, trimming and landing operations are effected.

It will be realised that great care must be taken to avoid projections and rough surfaces on the inner hull structure, so as to prevent the gas-bags—in their continually changing positions—from getting torn.

Control and Power Cars

In rigid airships, right from the earliest day the propulsive force has been provided by power units situated in independent cars slung from the ship. One large unit—as in most marine craft—cannot be used, because up to the present the h.p. which can be efficiently transmitted through a single two-bladed airscrew at speeds of 80 m.p.h. is not greater than 800 h.p. To reach 80 m.p.h. in a 2,000,000 cub. ft. ship some 2,000-2,500 h.p. is required, which means, say, four or five 500 to 600 h.p. engines. The division of the machinery into separate units has advantages also from operational and maintenance points of view.

Static stability necessitates the placing of the power units below the hull, otherwise there would be certain advantages in keeping them well out to the side or even on top of the ship.

The advantage of two-bladed airscrews lies in the fact that they can be fixed in a horizontal position and so kept clear of the ground when landing.

The number and position of these cars has varied very greatly, and it was the Schütte-Lanz type that first separated the control car from a power unit. The Zeppelin ships until the most recent combined their control car with an engine car in a kind of double unit forward. In R.38 we went further than the Schütte-Lanz principle by making the control-room a portion of the keel of the ship. In R.36, as in the "Bodensee" and "Nordstern," the control-room occupied the forward end of the passenger accommodation.

In the control car one finds the steering wheel for working the rudder, a similar wheel usually on the starboard side for operating the elevators, chart table, the various navigation, barometric, thermometric, etc., instruments—numbering 27 in R.38—electric switchboards and junction boxes, bomb release board, "toggles" for operating gas and water ballast valves for releasing gas or water ballast to adjust altitude or trim of ship. The wireless cabin also usually occupies the aft end of the control-room.

In the early Zeppelins the power units were installed in cars on the centre line, but the propellers were supported in brackets erected on the hull structure at the sides of the ship. The transmission was effected by gearing and long transmission shafts. This system has since been supplanted by direct or gear-driven propellers fitted at the stern of each car. All British rigids have used this system, the R.9 and R.23 classes having swivelling propellers at the sides of the cars driven through bevel gearing.

The power cars should of necessity be designed around a power unit, and only what is absolutely essential should be installed, so as to secure the smallest possible car and so save weight as well as head resistance.

There is no possibility of embarking on a discussion of the actual engines beyond stating that so far the British Airship Service has had to put up with aeroplane engines, which are eminently unsuitable for airship work. No rigid airship engine has yet been installed. R.38 had six 350 h.p. Sunbeam Cossack engines, one in each of six power cars. The amidships pair were fitted higher and further apart than the forward and after pairs, so as to allow their airscrews to run uninterfered with by the slipstreams of the forward pair. The airscrews in these amidships cars were also arranged to run astern. All power cars are in communication with the control car by means of telephone, electric buzzers (Klaxton or Dean horns) and the ordinary engine-room telegraphs.

There is no doubt that the ideal airship engine of an internal combustion type must use heavy oil. There is an obvious desire to employ an engine of the Diesel principle, and research and experiment is in hand at the moment to produce a satisfactory unit for the new ships. In the future it will be necessary to design interchangeable power cars and an easily get-at-able engine so that repairs can be undertaken without the laying up of a ship for any length of time—in fact, as has been proved in the case of R.33, such repairs could be done while the ship is lying to a mast. These points are being seriously considered in the design of R.101.

Car Suspensions

The question of car suspensions and the means of taking the thrust from the airscrews has always been an interesting one. The Germans take the thrust through their strut system. We adopted in our later ships the thrust wire running aft from the centre of the boss of the airscrew, which is of course far simpler and worked very satisfactorily.

Mooring Masts

As affecting the design of the bow structure of the ship, a few remarks about bow mooring will not be out of place. A certain amount of difficulty has always been experienced in landing and handling the ship on the ground, although it can be navigated in safety in very strong winds whilst in the air.

It was mainly due to the genius of Major Scott that we set to work to design a mooring masthead for large rigid airships, and the one erected at Pulham, on top of the old mast constructed by Messrs. Vickers some years before the war, was our first attempt; and crude as it was, it proved extraordinarily successful, and clearly established the fact that a method of mooring ships in all weathers had been evolved. A mooring mast renders a ship independent of her shed, as a sea-going liner is of her dry dock, until such time as it is necessary for her to be overhauled or repaired and, further, it reduces the number of men required to land and handle her from 300 or more to about 10, a distinct saving when the commercial side is being considered.

Up the mooring mast run pipes to supply hydrogen, petrol and water to the airship as necessary, flexible connections being provided at the top to connect on to the corresponding mains in the ship.

In the new Cardington mast, as in all future masts, lifts are provided to convey passengers and goods up to the top platform from which access to the ship is obtained by means of a brow similar to that used on a landing stage.

The method of mooring to a mast is as follows:—

About 600 feet of 7-ton F.S.W.R. is wound round a winch drum fitted in the bow of the ship. A similar length is wound round the drum of a power winch situated at the base of the mast. The ship approaches the mast coming up into wind, the free end of the mast wire is lying out on the aerodrome to leeward. One portion of a patent snatch connecting link is fitted to the free end of the mast wire.

When the ship is over the aerodrome its wire is dropped and the two portions are coupled together by two or three hands as soon as possible and the ship is then allowed to rise until the wire rope is taut, her engines keeping her just head-into-wind. The ground winch is then started and the bow of the ship hauled down until the conical fitting on the nose houses into the cup at the end of the swinging telescopic arm of the masthead. To check the "hunting" as the nose approaches the masthead side guys are paid out to bollards, of which a ring is placed around the base of the mast. The ship's nose is therefore virtually at the apex of a triangular pyramid. Hauling is continued until the telescopic arm closes up and the whole becomes solid with the rotating top of the mast. The ship is then free to swing round with the wind, and all that is necessary is to keep her properly trimmed, slightly tail down so that any gusts will tend to lift her tail instead of depressing it, in which case it might come into contact with the ground.

There are many other details regarding mast mooring with which there is no time to deal just now. Major Scott had dealt very fully with the whole subject in his lecture before the R.Ae.S. which is recorded in their journal of last August.

Conclusion

I have endeavoured in a relatively short space of time to cover an immense area of ground. You will realise how a lecture of this duration could deal with one only of the many hundred details involved in the consideration of the design, construction and operation of airships. Many details I have had to leave untouched. I would close with a word that I hope you will think of an airship as complementary to and not necessarily a competitor against the heavier-than-air machine.

Paper read before the Yeovil Branch, at Yeovil, on the 28th January, 1927.

MAGNETOS

BY A. P. YOUNG, O.B.E., M.I.E.E., M.I.A.E.

(BRITISH THOMSON HOUSTON CO., LIMITED).

In his opening remarks, Mr. Young stated that the magneto was an electrical machine of very small compass for converting mechanical energy into electrical energy at a very high potential. The electrical energy appears as high tension sparks which occur at regular intervals and in synchronism with the movement of the pistons. Each spark is the result of a very rapid rise of pressure in the secondary winding of the armature of the magneto. To-day magnetos are being produced capable of giving regularly 16,000 sparks per minute or 270 sparks per second.

Historical

All electrical systems of ignition are direct descendants of Faraday's great discovery of electro-magnetic induction made during the autumn of 1831, when, for the first time in the world's history, he succeeded in producing a spark by electro-magnetic means. He was experimenting with his classical iron ring wound with primary and secondary when it was possible to obtain a tiny spark between two carbon pencils separated by a very small distance and connected to the ends of the secondary.

The first system of electric ignition ever used was devised by Lenoir in 1860. He utilised the high tension spark of a Ruhmkorff coil for ignition purposes, employing a high tension distributor for connecting the secondary winding first to one plug and then to the other. It is worth noting that the modern battery system of ignition now used most extensively in America is strikingly similar to the old Lenoir system, even to the detail of introducing an extremely small air gap between the rotating metal brush and the distributor segment—a method of distribution that is now employed on magnetos. Lenoir was also the inventor of the spark plug, and the type of plug which he designed for use in conjunction with his ignition scheme of 1860 had all the features of the modern spark plug.

Marcus appears to have been the first man to construct a magneto for ignition purposes. It was a low tension machine, having the now familiar form of H armature, the current induced in the winding being broken at pre-determined intervals in the cylinder by a system of cams and levers. About 1887 Robert Bosch commenced the manufacture of this type of magneto for slow speed engines. The high tension magneto did not appear until about 1902 when Bosch patented a magneto with primary and secondary windings and having a contact breaker to open and close the primary circuit at pre-determined intervals.

Prior to the war, only one or two firms in this country were interested in the manufacture of magnetos and the numbers produced were actually very small. At the outbreak of war engineering firms in this country were called upon to take up the manufacture of this type of apparatus, and since that period the British magneto industry has grown at a phenomenal rate and to-day is fully capable of meeting all the demands of the automobile, aircraft and similar industries.

Electro-Magnetism and Electro-Magnetic Induction

Before passing on to deal with the operation of the magneto, the Lecturer explained the principles underlying electro-magnetism and electro-magnetic induction. He showed how electric and magnetic effects are inseparably

associated one with the other. The classical experiments of Faraday, illustrated by slides, clearly proved that so long as the magnetic flux linked with a conductor or winding is changing, an electro-motive force is induced in the conductors. Thus, to induce an e.m.f. in a winding, there must be a change in the number of lines of magnetic force linked with the winding. The induced e.m.f. is proportional to the rate of change of flux and the number of conductors linked with the magnetic field.

The Principles of Operation

The high tension magneto consists essentially of—

(1) A permanent magnet system.
(2) An iron core wound with primary and secondary windings.
(3) A contact breaker to interrupt the primary circuit at pre-determined intervals.
(4) A distributor for delivering the high tension current to the sparking plugs of the engine.

The earthed primary contact is actuated by some form of cam, so that the primary circuit is continually being opened and closed.

The iron core carrying the armature windings may either revolve as in the case of the rotating armature magneto or remain stationary as in the Polar inductor and rotating magnet types.

The flux reverses its direction through the iron core of a rotating armature magneto twice each revolution, there being two armature positions, exactly 180° apart when the flux through the core is zero, and two other positions, also 180° apart, when the flux reaches positive and negative maximums respectively.

The e.m.f. induced in the primary reaches a maximum twice each revolution, corresponding to the armature positions when the rate of change of flux is greatest. The maximum attained in the second half revolution will be opposite in polarity to that of the first half revolution, since the flux is threading the core in the opposite direction.

If the primary winding be short-circuited a current will be generated in it that will vary in amplitude in a somewhat similar manner to induced e.m.f.

(*a*) *Function of the Contact breaker.*

The purpose of the contact breaker is to open and close the primary circuit for definite periods and generally the contacts are closed when the induced e.m.f. is zero, that is, when the flux through the core is a maximum. The primary current reaches a maximum a short interval after the induced e.m.f. is a maximum or when the armature core flux is zero. The contacts are arranged to open in the advanced timing position at low speeds, when the current is a maximum, or when the armature is 5 to 10 degrees beyond the "dead centre" position.

(*b*) *Effect of Primary Current on Magnetic Flux.*

From Lenz's law we know that the current induced in a winding is of such direction as to oppose the change in flux producing it. Consequently the current induced in the primary winding tends to oppose the change of magnetic flux through the core and in so doing distorts the magnetic flux in the direction of rotation. Immediately the contacts separate the current ceases and the flux rapidly reverses its direction through the core.

(*c*) *The Function of the Condenser.*

Just as the primary current tends to oppose any change in the number of magnetic lines linked with the primary, so also is any change in primary current

opposed by the magnetic field associated with it. Thus, when the contacts separate, there is considerable resistance offered to this sudden change in current and in consequence a very high voltage is induced in the primary winding immediately the contacts separate. But for the condenser, which is connected in parallel with the primary winding, the current would persist in the form of an arc.

This arcing, besides being very destructive, also prevents the rapid reversals of the magnetic field, through the armature core. The condenser actually absorbs the initial rush of current when the contacts separate and prevents a too rapid rise of the induced primary voltage, until the contacts have separated appreciably.

(*d*) *Induced Secondary Voltage.*

The very high voltage necessary to initiate a spark at the plug in an engine cylinder is induced in the secondary winding as the result of the very rapid reversal of the flux through the armature core. The secondary winding usually consists of 8,000 to 10,000 turns of very fine enamelled covered wire, and on present day magnetos a voltage of the order of 8,000 volts is induced in this winding at a speed of about 50 r.p.m. The effect of the primary winding in speeding up the flux reversal through the coil will perhaps be better appreciated when it is stated that without the primary winding a speed of something like 10,000 r.p.m. would be necessary to induce such a voltage in the secondary winding.

The High-Tension Spark

The spark produced by a magneto or other ignition unit essentially consists of two components, viz. :—

(1) The initial or capacity component due to self-capacity of the secondary winding plugs and leads, which lasts for an infinitely short time only. This is the most active and actinic component and is the component of the spark that ignites the charge in the cylinder.

(2) The inductive or flamy component which may persist for quite an appreciable time.

Under ideal conditions the spark energy required to ignite the charge in the engine cylinder is very much less than that given by the average magneto. In practice, however, the plugs are leaky and ample energy is necessary to ensure a spark under adverse conditions.

Assuming no losses, the whole of the energy stored magnetically in the primary would appear in the secondary spark. This would be equal to $\frac{1}{2}$ L.I.B. where

L = primary self-inductance at "break" and
IB = value of the current at the instant of "break."

Actually something like 75 per cent. of this energy appears in the spark.

Types of Magneto

The three chief types of magneto are :—

(1) The Rotating Armature type.
(2) The Polar Inductor type.
(3) The Rotating Magnet type.

(1) *The Rotating Armature Type.*

This is undoubtedly the most familiar type, the primary and secondary windings being wound on an H score, which rotates between the poles of a permanent magnet. Two sparks per revolution can be obtained. The rotating armature magneto finds a wide application on engines of 1 to 6 cylinders.

(2) *The Polar Inductor Magneto.*

The Polar Inductor Magneto was specially developed by the B.T.H. Co., Ltd., during the war, for use on 8 and 12-cylinder aircraft engines. The armature core in this case is stationary. For each quarter of a revolution of the rotor shaft there is a complete reversal of flux through the armature core.

The robust construction of this type of magneto, together with the fact that it is capable of producing four sparks per revolution, in which case the running speed is half that of the rotating armature, renders it eminently suitable for high speed multi-cylinder engines.

It is used almost exclusively in this country on aircraft engines of 7, 8, 9, 12 and 14 cylinders.

(3) *The Rotating Magnet Magneto.*

Whilst this type is by no means new, it has come into greater prominence since the advent of cobalt steel. Theoretically this magneto can be designed to give four or even six sparks per revolution, but practical difficulties limit it to a two-spark machine.

As in the polar inductor design the armature is stationary and the flux reversals in the armature core are produced by the rotation of a permanent magnet, fitted with laminated poles, between the armature core poles.

Its field of application is chiefly confined to four and six-cylinder engines.

Improvements Effected by British Designers

During the past decade many improvements have been effected by British designers. Briefly these are as follows:—

(*a*) The introduction of laminated magnet poles. This has greatly improved the low speed sparking characteristics concurrently with a reduction in weight.

(*b*) Unit construction of the body casting and distributor end-plate, giving greater strength and more accurate alignment of the armature bearings.

(*c*) Improved design of cams. In place of the short flat segmental cams, long cams machined from a continuous ring are now employed. This improvement has resulted in increased efficiency, higher operating speeds and less wear.

(*d*) The use of the spark gap type of distributor has overcome troubles due to tracking; obviated the necessity for periodical cleaning and rendered the magneto less sensitive to oily or sooty plug conditions.

(*e*) The elimination of rivets in condensers has rendered this unit very much more reliable.

(*f*) Special treatment of the fibre rocker bush and carefully chosen limits for the hole in the lever and the diameter of the bush has eliminated almost entirely troubles due to sticking rocker arms.

Trend of Development in Regard to Aircraft Magnetos

Two very important developments have taken place in regard to magnetos for aircraft. The first is in the direction of reducing weight and the second is the elimination of interference of the magneto with the wireless apparatus on board.

(1) *Reduction in Weight.*

As previously mentioned, the use of cobalt magnet steel results in a material reduction in weight, and advantage has been taken of this in the latest designs of magnetos for aircraft purposes. In this respect, it is of interest to mention

that the weight of a certain design of magneto for 12-cylinder aero engines has been reduced by $3\frac{1}{2}$ lbs. as a result of the use of cobalt steel magnets.

(2) *Shielding of Aircraft Magnetos.*

In order to prevent the operation of the magneto from interfering with wireless apparatus, it is necessary not only that the magneto should be completely shielded by metal casing, but also that the metal braided ignition cables be employed. Owing to the greatly increased distributive capacity of the high tension circuit in consequence of this shielding, the efficiency of the magneto, particularly at low speeds, has been seriously impaired. The severity of the service of the magneto has, from an insulation standpoint, also been greatly increased. These difficulties have, as a result of careful attention to the design of the electrical and magnetic circuits, now been overcome, as evidenced by the fact that aircraft magnetos are now giving excellent service over a range of spark frequency from 6 to 300 sparks per second.

Impulse Starters

In cases where the starting conditions are particularly severe, such as on heavy commercial vehicles, tractors and motor boats, the use of impulse starters has been very effective.

This type of apparatus usually takes the form of an attachment to the magneto and essentially consists of driving and driven members coupled together by a spring, with some means, such as a pawl and stop, to temporarily arrest the movement of the magneto armature and then release it suddenly. A typical example of such a device was illustrated, in which a pawl on the driven member engages a stop and momentarily arrests the armature. Further rotation of the driving member winds up a helical spring. Secured to the driving member there is a cam, which bearing on a plunger attached to the pawl, releases it from engagement with the stop after a pre-determined angular displacement. The magneto armature then "flicks" forward very rapidly and in so doing produces an intense spark at the plug points.

As soon as the engine accelerates the pawls are thrown out by centrifugal force from further engagement with the stop and the magneto is then driven as through a direct coupling.

Automatic Timing Control

During recent years developments have taken place in the direction of automatic timing control. The automatic timing device, which can be supplied either as an attachment to the magneto or integral with it, will undoubtedly find increasing application in the very near future.

Such devices are designed on the centrifugal governor principle to advance automatically the driven member, which is attached to the magneto shaft relative to the driving member.

The use of a scientifically designed automatic timing device results in:—

(*a*) Improved engine efficiency and more economical running.

(*b*) Improved acceleration, thereby minimising gear changing.

(*c*) Exceptionally low road speeds on top gear.

(*d*) Simplified driving and thereby greatly enhancing the pleasure of driving.

(*e*) Easy starting. The necessary retard is obtained on the automatic control and therefore the magneto, being fully advanced, gives a spark of maximum intensity.

YEOVIL BRANCH

Paper read before the above Branch at Yeovil on the 27th October, 1926.

ERECTION AND RIGGING OF AEROPLANES

BY W. G. GIBSON, ESQ., A.R.AE.S.

(WORKS MANAGER, WESTLAND AIRCRAFT WORKS).

The paper to be given this evening will describe the methods used and the sequence of operations in erecting a machine which has been delivered new or overhauled from the makers, as distinct from carrying out repair work.

It is proposed to commence with the methods used for checking the correct assembly of components and the rigging of an erected machine. We will assume that a machine has been delivered to the owner in a dismantled condition; that is to say, the wings, tail units, undercarriage and centre section have all been received separately, and it is necessary to entirely re-assemble the machine. It is assumed that the machine is in good condition and that each component has been approved already.

The fuselage should be mounted on trestles sufficiently high to permit of the undercarriage being tried up underneath it. The majority of machines will have definite lifting or jacking points indicated on the fuselage; if not, the machine should be held on strong points and directly under a vertical or nearly vertical strut in such a manner that the load is distributed along the longerons several inches. The trestles should also be placed in such a way that the erection of the undercarriage to the machine is not interfered with and, if the machine already has its engine installed, one trestle should be placed sufficiently far forward to ensure that there is no danger of the machine tilting forward while work is being carried out upon it.

It should be levelled fore and aft, and for this purpose it will be necessary to find out the correct levelling points if these are not already clearly shown by the manufacturers of the aircraft. For this purpose reference should be made to the rigging diagrams usually supplied by the manufacturers of the aircraft. It will probably be found that a certain section of the top longeron is used as a horizontal datum line fore and aft or that certain vertical struts on either side of the fuselage are marked to give a horizontal lateral datum line. In any case no assumption should be made without definite information.

The machine should be roughly levelled fore and aft, using a spirit level with not less than 12in. base for this purpose, and both sides of the fuselage, if possible, should be checked as there may be slight differences. If this is the case, the average should be taken between the two sides. The machine should then be checked for lateral or cross levelling, and for this the usual course is to place a straight edge across the top longeron at least two points as close to the centre of the machine as convenient.

After the cross levelling has been completed, fore and aft levelling should again be checked and any slight adjustment made which is considered necessary. It is not considered good practice to use pieces of paper or fabric, etc., for packing material under the trestling points, as these will probably sink and throw the machine out of level before work has proceeded very far.

Having ensured that the machine is truly level, both laterally and fore and aft, the erection of the undercarriage may now commence. It will be assumed that the undercarriage is complete and that it is actually already fitted with its shock absorbers, fairings, etc. If it is of the "V" type it may now be pinned or bolted directly into position, care being taken to see that no straining is necessary to get it into its proper position. It is, of course, assumed that, as this machine has already been erected, no bedding of struts, fitting of pin joints, etc., are necessary. The undercarriage having been bolted in position, the cross bracing may now be fitted. The wires should be pinned on and a plumb bob dropped from the centre of the fuselage, this point being found by measurement. The centre of the axle should be found by measurement and the bracing wires adjusted so that the plumb bob coincides with the axle centre point. In this connection it is not necessary to use a centre punch and a 2 lb. hammer to mark the centre of the axle, a pencil line will serve the required purpose.

The wires should be adjusted to only sufficient tension to hold the undercarriage rigidly. Later on a few general hints will be given dealing with the tensioning of wires, but it should be pointed out that a screwed wire is a mechanical instrument with which tremendous forces can be set up, and very serious damage may be caused through over-tensioning, and initial stress may be set up which will cause an already overload structure to collapse on a heavy landing.

Having fitted the undercarriage the machine may now be jacked up, using the undercarriage as the front supporting point, as it will probably be inconvenient later on to remove the front trestle after the wings are fitted. Suitable points on the undercarriage should be selected for this purpose; unsuitable points, among others, are the axle, which is liable to give through its shock absorber with certain types of undercarriages; axle fairing, which is not made to take such loads; and on no account should the machine be supported on its wheels as a permanent level cannot be maintained. In any case, the support should be fitted underneath the undercarriage struts. This re-jacking of the fuselage will necessitate re-levelling before the wings and tail units can be attached. Having done this, the tail may be bolted on.

It will be assumed that the tail is of the adjustable variety. The tail should be bolted and split-pinned at the correct points and the bracing wires attached and split-pinned ready for adjustment. The bracing wires should then be adjusted so that the front and rear spars are horizontal. This can be tried out by means of as long a straight edge as possible, using packing blocks located on the spars and not over the ribs, and a 12in. spirit level. The same remarks with regard to the tensioning of wires also apply here.

It will not be necessary to check the angle of incidence of the tail plane as this has already been fixed by the manufacturers of the machine, but the check should be taken after adjusting the spars to bring them level fore and aft between the front and rear spars in case there is any slight difference in each angle of incidence on either side.

This adjustment having been carried out, it is necessary to ensure that the tail plane is square to the centre line of the fuselage, and this is best carried out by taking a diagonal measurement from a definite point on either side of the tail plane rear spar which should be checked from the centre to ensure accuracy to a point fairly well forward on either side of the fuselage. If this measurement is found to be incorrect it will probably be found that the fixing points of the tail plane allow of sufficient adjustment in the way of packing washers, etc., to correct this fault. If not, the tail plane spars should be checked for straightness and, if these are correct, the fault will probably lie in the fuselage, but this is unlikely with a machine newly delivered.

The fin may now be attached in the case of a machine whose tail plane bracing does not depend on the fin. If, as in some cases, the fin carries upper tail plane stays, it should be fitted before the trueing up of the tail plane commences, and the only point which requires special attention in this connection is to ensure that the fin is truly vertical, which may be done with a spirit level or plumb bob; and in cases where the fin carries the rudder hinges, to ensure that these hinge points line up with the lower hinge points on the fuselage. This is best checked by a straight edge as it is not unusual for the rudder hinge line to be slightly out of vertical.

The elevators and rudder may now be pinned on, care being taken that the hinge points are greased before assembly, and that any packing washers necessary are fitted so that there is no end play in the hinges except in cases where all the play is taken up on one hinge.

The rudder will be fixed in the same way, and it is wise to lock both rudder and elevators so that the hinges will not be strained before the control cables are coupled up. The control cables should now be adjusted to the elevators and rudder in such a way that the movements required by the makers are obtained.

The wires should be just sufficiently tight for the controls to operate without backlash of the controls, but the tautness which is necessary for the undercarriage and wing bracing is not here required, as too much friction would be set up in the controls.

The same remarks apply to the rudder cables, and before these are locked they should be checked through from end to end to ensure that they line up properly with the fairleads and pulleys, and that the latter are properly lubricated and free on their bearings. It is not nowadays considered good practice to lubricate the cables running through the fairleads, as it has been found that the lubricant mixes with dust and forms an abrasive mixture which wears out the cables far more rapidly than if they are left unlubricated. This cannot be taken as a really definite pronouncement as there may be special cases where lubrication is preferable, but as a general rule it is certainly the case that unlubricated cables have a longer life.

The machine should now again be checked for level and the rigging of the centre section and wings may be commenced.

Rigging has two objects. Firstly, the adjustment of the levelling and controlling surfaces to the designed position, and secondly, the adjustment of the tie-rods, wires, etc., to ensure a correct distribution of the loads throughout the structure. It is not always possible to obtain an exact adjustment of the surfaces to the designed position without unnecessarily straining the structure, and it is therefore usual to allow limits which normally are given by the manufacturer. For instance, no attempt should be made to correct the stagger of a machine which is only $\frac{1}{8}$in. out when doing so will necessitate undue straining of wires and struts. The centre section struts will now be dropped into their sockets and attachment made on the fuselage, care being taken that the struts are put into their correct positions. The centre section should then be dropped on over the struts, the pins fitted if pin joints are used; if of the De Havilland type, the joints should be examined to ensure that the load is actually taken on the pin; or if of the Avro type, to check by means of the spotting hole that the struts actually bed in their sockets.

Plumb bobs should now be dropped either from the end of the spars or from definite holes in the spar fittings down the sides of the fuselage, and the cross bracing wires between the two front struts and the two rear struts, and adjusted so that a measurement taken on either side of the fuselage front and rear gives equal results, showing that the centre section is located correctly over the centre line of the machine.

The incidence bracing may now be adjusted to give the required stagger to the centre section. This is done by dropping a plumb line from the leading edge from the centre section on either side or from the front spar fittings on either side and measuring from the plumb line to the front spar fittings in the lower plane.

The incidence wires should be adjusted until the makers' dimension is obtained within the limits set down, which will vary with different types of machines, and the cross bracing again checked to ensure that no further adjustment is required. If this is correct and the spars of the centre section are level when tried on top, using packing blocks on the spars or the spar fittings and a spirit level, the centre section may be locked up.

Except where it is absolutely impossible to use anything else, ribs should not be used for levelling up, as they not only may vary, but the amount of fabric on them sometimes varies considerably, whereas with a spar one is usually safe in assuming that there is only one thickness of fabric between the levelling block and the spar.

This point reached, the erection of the wings may now commence. Methods of rigging vary. For the ordinary single-engined tractor machine there are two methods in general use. One is to assemble the top and bottom planes together with their struts and wires into box structure, standing on the leading edge of the wings, and to mount this whole structure as a unit. This is a very good method if the machine has previously been erected and dismantled with one wire out of each bar left dead length. Otherwise it is generally preferable to attach one wing at a time with small machines. The most satisfactory method is first to attach the lower plane using a trestle under outer strut position to keep the wing approximately at the right dihedral angle.

The wing attachment of the machine can be broadly divided into two types. One, pin joint attachment, which consists of a simple hinge through which the pin is fitted; and the other and more common method for modern commercial machines is the flitch plate attachment, as used on Avro and DH.9A machines. With the latter type of joint, care is necessary to enter the wing at the right angle in order that the flitch plates may not be strained or bent. If they fit so tightly in between the flitch plates as to strain them apart it may be necessary to open up the fabric and very slightly reduce the amount of packing on the end of the spar. This will not be necessary if the machine has already been erected.

It is not good practice to use tommy bars for straining the wings into position, as the elongated holes, which are bound to be the result of this practice, do not find favour with the A.I.D., moreover, they prevent the bolt from being fairly loaded. If tommy bars are necessary, they should consist of rods the same size as the bolt which is to be used with a very long taper, and they should not be driven in with a hammer; neither is it permissible, if the holes do not line up satisfactorily, to bend the bolt before putting it in, as it will probably cause trouble later on and may give you the trouble of looking for another job; also, if the machine has already been erected at the makers' works this should be unnecessary.

After the wing is bolted in position, the end fittings of the spars should be checked to see that the end face of the spars bears properly against the metal fittings or the stub spar to which it is bolted, and a clearance of more than 0.010in. should be rectified by fitting further thin packing on the end of the spar. This is not likely to be necessary with new machines.

The top plane may now be lifted into position and entered into its attachment points, interplane struts meanwhile being slipped in to help take the weight, after which the bolting of the root attachment of the wing may be proceeded

with as for the lower plane. The same operation can now take place on the other side of the machine, so that we now have the four wings bolted to the fuselage and centre section with the interplane struts in position, but without any wires attached.

Before proceeding any further, it will be useful to go through certain of the terms used for rigging main planes in order that their meaning may be perfectly clear.

The Angle of Incidence is the angle to which the wing is inclined to the datum line of the machine for the purpose of rigging.

The Dihedral Angle is the name given to the outward and upward slope of the wings, and is usually measured by the angle from the horizontal, though strictly speaking it should be the included angle between the two wings.

Stagger is the amount which the top wing is placed forward of the lower or, in some cases, behind the lower.

Lift Wires are the wires running from the fuselage upward to the top plane and from the base of the inner struts upward to the top of the outer struts.

Landing Wires are the opposite wires to the lift wires and, when the machine is on the ground, take the whole weight of the wings.

The so-called Incidence Bracing Wires are the wires between the front and rear struts and their function is chiefly to equalise loads between front and rear flying wires and to transfer the load to the front flying wire should the rear flying wire break and vice versa. It will therefore be seen that the incidence bracing is not so unimportant as one often hears the opinion expressed.

Before proceeding with the adjustment of the bracing wires it will be necessary to find out the angle of incidence, the dihedral angle of the wings and also to ascertain whether there is any "wash-in" or "wash-out." The terms "wash-in" and "wash-out" refer to increase or decrease of the angle of incidence towards the tips of the machine which may be made for various reasons.

In the majority of single-engined machines a very slight adjustment of this kind is necessary to counteract the engine torque reaction, *i.e.*, assuming that engine rotates in clockwise direction, there will be a tendency for the machine to rotate in the opposite direction. This tendency is to be corrected and the simplest way to do this is to vary the angle of incidence of the wings.

In the larger single-engined machines this tendency is not so marked as the machines can usually be rigged to the designed angle of incidence throughout, adjustments being made afterwards to suit the pilot's requirements.

It is usually more satisfactory if the machine is to be in the hands of the same ground engineer or the same company, to make gauges for checking these angles. In the case of the dihedral angle, this is best obtained by using a tapered strip of wood between two and three feet long with blocks on the under surface on either end which can register on the spar, the taper being such that, when the wing is at its correct dihedral angle, the upper face of the strip is horizontal and can be checked by a spirit level.

The angle of incidence can best be checked by a gauge and its exact form will depend on the section of the wing and the angle of incidence.

If no data is available on this point, a gauge may be made on the assumption that the root fixings on the fuselage will give the correct angle of incidence, and if the wing is entered into the fuselage root fittings and trued up to its correct dihedral angle on both spars, a gauge made so that the top face is horizontal

when tried up as close as possible to the root fitting will usually give sufficiently accurate results.

Having made or obtained these gauges, the actual rigging of the machine presents very little difficulty. The bottom plane should be trued up on the trestles so that the wing lies at its correct dihedral angle and correct angle of incidence on either side. The landing wires should then be attached and tensioned up very slightly; the flying wires may then be screwed up so that they are just tight, and the bottom wing may then be tried throughout for dihedral angle and angle of incidence with the gauges and slight adjustments made until the required angles are obtained, the trestles meantime being removed as the landing wires are now taking the weight of the wings.

Before proceeding further, the leading and trailing edges of the wing should be sighted along from the tip to see if these are straight. If not, either the leading or trailing edges are slightly warped or the trueing up is at fault and should be adjusted.

The stagger of the machine now requires adjustment, and this is done by dropping a plumb line over the leading edge of the top plane to below the level of the lower leading edge at a point near the tip and also about halfway between the tip and the fuselage. It is assumed that the centre section has already been checked for stagger, as previously mentioned. Measurements may now be taken from the lower leading edge to the plumb line and the incidence bracing adjusted until the required measurement is given. If the centre section has been rigged correctly, it should not be necessary to strain the wings in order to obtain the required measurement and, should the rigger be left to the choice of leaving the machine with its stagger not more than $\frac{1}{8}$in. out or of straining the incidence wires to get it into the exact required position, he should be content with getting the stagger within $\frac{1}{4}$in. of the required position, as overstrained wires will affect the machine far more seriously than a small error of, say, $\frac{1}{8}$in. in a stagger of 6in. or so.

All the required adjustments having been made to obtain the aforementioned result, it is now only necessary to see that all split pins are properly opened up, lock nuts tightened and that all fittings line up properly with the bracing wires to which the wires are attached. An error of not more than $\frac{1}{2}°$ is permitted on wiring lugs, etc., and if this is exceeded, the lugs should be changed or, if no other is available, it should be taken for re-setting to the required angle and normalised. Should it be marked in such a way as to denote that it is made of an alloyed steel such as S.4, this procedure cannot be followed as a special heat treatment is required, and in this case the fittings must definitely be changed while the faulty ones are being rectified by approved methods of heat treatment.

If a " wash-in " or " wash-out " of incidence is called for on the machine, the procedure to be followed will depend on the amount, but normally this is very small and will consist of an adjustment of not more than half a turn decrease on the flying wires on one side in the outer bay, and half a turn increase on the flying wires in the opposite outer bay always on the rear spar.

The front spar is invariably rigged to the correct angle of dihedral throughout. The term " wash-in " refers to an increase of angle to give greater lift on the side to which it is applied. The term " wash-out " refers to a decrease of angle of incidence to slightly lessen the lift on the side to which it is applied.

If the required " wash-in " or " wash-out " cannot be obtained by half a turn on the outer bay, both inner and outer bays must be adjusted, care being taken to see that the rear spar is not bent in the process. This can be seen either by sighting the trailing edge of the wing or, if this is warped, by applying a straight edge or a line to the upper or lower surface of the wings in the region of the rear spar.

Struts should be examined for bowing, which can usually be detected by looking at them. If there is any doubt about this method owing to the struts being tapered, the best method is to hold a mirror at one end of the strut which will invariably show the slightest deviation from the straight. Bow in struts cannot be permitted to any extent, and a good general ruling is not to exceed a bow of 1 in 1000, though this depends entirely on the circumstances and the size of the strut. A bowed strut should again be examined for bowing after removal. If this is no longer apparent there is evidently either a mis-adjustment of the wires resulting in increased tension on one side of the strut bearing to the other which can, of course, be corrected or, in the case of struts bedding on to a flat base into the sockets, the bedding is not even. This, again, can usually be rectified very easily. If the strut has definitely bowed after removal no attempt should be made to strain it, and it should be replaced by one which is not defective.

It is not usually necessary to check the upper plane if the lower one is correctly adjusted to give the required measurements unless the machine is of an experimental type for which interchangeability cannot be guaranteed, and so it is not unusual to find that the angle of incidence of the top plane will vary very slightly from the angle of incidence of the bottom. Should any doubt be felt, however, a check may be taken, and if differences of more than 15 minutes are found in the angle of incidence, steps should be taken to rectify these either by re-adjusting the wiring so that the error is distributed between the top and bottom wings, or by replacing the struts by those of a more suitable length.

As we are, however, dealing with a machine which has been erected and passed at the makers' works, this is not likely to be the case. Before leaving the main plane rigging, all fittings should be finally looked at to ensure that they are properly seated at the spars as if the machine has been in storage it is possible that the timber has shrunk and, if this is the case, the holding down bolts, etc., should be tightened up until the fittings are bedding properly, but not sufficiently to pull them into the spars. On the majority of biplanes certain of the bracing wires cross so that they are practically touching each other, and various means are adopted for separating them. Before the rigging of the wings is left these should be attached, care being taken to see that before use the possibility of the wires touching each other is eliminated. During the inspection of the machine these should periodically be examined to ensure that they have not become loose or worn to a sufficient extent to allow the wires to touch one another, as the vibration experienced in flight will very shortly allow the wires to rub together sufficiently to set up considerable local wear, reducing the strength of the wire. Should such a case of this be found, the wire must be taken out, scrapped and a new one fitted.

It has been assumed that the ailerons are already fitted to the wings. If this is not the case, they should be pinned on, split pinned, the hinges properly lubricated and the aileron locked to the fixed trailing edge of the wing so that the hinges are not strained. Needless to add, whatever means of locking is adopted must be removed before trueing up of the controls is finished.

The control cables may now be coupled up to the aileron at the outer end and to the controls in the fuselage at the inner end, care being taken to see that they are not twisted or bent, and that they line up properly with any pulleys or fairleads. Pulleys should be lubricated and made free to reduce the working friction to as little as possible, and the controls may then be adjusted. It is usually the practice to set the ailerons with a slight droop; in other words, when the machine is at rest on the ground the trailing edge of the aileron should be slightly below the trailing edge of the fixed portion of the wing. This varies for different makes of machines; but with the single-engined type of machine it will vary from between $\frac{1}{2}$in. to 1in., according to the makers' instructions. If

there is no available information on this point, it is reasonable to commence with a droop of about ½in. for the Avro type of machine and machines of similar size, and about 1in. for machines similar in size and construction to the DH.9A. The droop is given to counteract the extension and settling down of the controls in flight which results in an actual lengthening of the control cables and connections. If no droop was given the ailerons would probably lie slightly above the fixed portion of the wing in flight with a consequent loss in efficiency to the portion of the wing to which they are attached. The weight of the ailerons while on the ground is sometimes taken by springs, but more usually by a balance cable running through the top plane from aileron to aileron and these should be adjusted to have the minimum possible tension when on the ground, owing to the fact that this ruling applies to all control cables. The gap wires which couple the ailerons to the top and bottom wings should be set so that the trailing edges of both top and bottom ailerons line up with their respective wings.

Should an aileron be winding, that is to say, slightly twisted, so that it does not line up truly with the fixed portion of the wing, it should be removed and opened up for correction. If the wind is very slight, it is occasionally possible, where ailerons have two inter-aileron wires attached, to take out the wind by means of these wires, but this requires considerable care and must not be done if undue tension has to be applied to either the inter-aileron or the control wires.

Having coupled up the controls, it is necessary before locking them to see that the makers' movements are obtained or, if these are not available, to see that the fullest possible movement is obtained on the control column from side to side of the fuselage or between any stops which may be fitted without undue effort.

It should be possible to operate the controls of any single-engined machine by gripping the top of the control column with the finger and thumb only of one hand, and if this is not possible investigation should be made to see whether friction is set up and to remove it, if, as occasionally happens, the cables inside the wings foul the stringing of the plane owing to these having been put directly in line with the run of the cables. In such a case the wings should be opened and the stringing cut and fresh stringing put in about 1in. on either side of the cable. It is also possible for the cable to have been so threaded through the wing that it is not taking up its correct line, and if this is the case, it should be taken out and properly fitted to clear such obstructions as stringing, rib members, etc.

If the movements of the aileron, as set out above, can be obtained and the controls function without undue friction and without backlash, which should not exceed ½in. on the top of the control column, the controls may now be locked up, and the whole of the machine finally gone through as a final check to see that everything is correctly locked up.

YEOVIL BRANCH

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WIND TUNNELS

BY W. WIDGERY, ESQ.

The wind channel and the whirling arm have been devised and perfected over a period of a number of years with a view to providing reliable aerodynamic data for aircraft designers. Of late years the wind channel has been used considerably more than the whirling arm.

In the two pieces of apparatus distinct methods are used. In the whirling arm the model is carried through the air, which is stationary, in a circular path by a long arm. In the wind channel, on the other hand, the model is stationary and a current of air is caused to flow past it.

Various types of wind channel have been evolved, but I intend to describe fully the English wind channel in its present form, as perfected by the National Physical Laboratory and the Royal Aircraft Establishment, Farnborough.

Description of N.P.L. Type

The wind channel consists essentially of a long square tube through which air is drawn by a fan. This fan runs in a cylindrical portion which is connected to the end of the tube by means of a cone or tapering portion. The cross sectional area of the passage at the fan is very much greater than the cross sectional area of the square tube portion. As I have said, the air is drawn through this channel, is expelled by the fan, and is sucked in at the other end. The end at which the air enters is turned back in a lip which is faired in to the square portion of the channel. This is to prevent any eddies being formed as air is sucked round the edge of the tube.

When the wind channel is housed in a small building, the air which is expelled from the fan returns through the building at a fairly considerable velocity, and it is therefore necessary to place behind the fan some form of distributing box. Where the building is very large, then the air returns to the mouth very slowly, so that the air entering the channel is almost stationary and the distributor can therefore be omitted. In the earlier channels this distributor box consisted of a square box built up of slats of wood. In several of the later channels this distributor box has been dispensed with and the building which houses the channel has been separated into two distinct portions by honeycomb wall made of bricks with alternate bricks omitted.

In order that the air which enters the channel may be entirely free from eddies, inside the entrance to the working portion there is placed a honeycomb made up like the separators in an egg box from pieces of thin sheet steel. The apertures in this honeycomb are approximately 3ins. square. The length varies, but would probably be of the order of one or two feet.

The fan itself is very similar to an ordinary aeroplane propeller and is driven usually by an electric motor, the speed of which is controlled by means of resistances. Where the source of electric power fluctuates or is at all erratic, occasionally the motor has been driven by accumulators.

The speed of the air in the channel is measured in the first place with pitot and static heads similar to those used on an aeroplane. This head often differs from those used on aeroplanes in one respect, *i.e.*, the two tubes are built up concentrically instead of being placed side by side as for an aeroplane. This is done purely for convenience. The ordinary type of air speed indicator as used on aeroplanes could be connected to these, but for greater accuracy a special form of water gauge is used. This gauge is called the Chattock manometer.

The blades of the fan are usually square and not shaped like those of an aeroplane propeller. Many experiments have been carried out to find the best shape for the fan and those in use are designed in accordance with the data obtained from these experiments. Often a honeycomb is found immediately in front of a propeller and exactly similar to that at the inlet of the inlet end of the wind channel. This is to prevent the propeller tending to whirl the air inside the working portion before it reaches the propeller. Frequently nowadays this extra honeycomb is omitted as it is not essential, and its place is taken by wire netting which prevents any solid object being sucked into the propeller. Occasionally the model under test flies down the wind channel and sticks on to the wire netting.

The Chattock manometer is a special form of U tube filled with water. The difference in pressure tends to force the water up one limb, thus lowering the level in the other limb. This flow of water is prevented by tilting the gauge with a micrometer screw. The pressure is measured by the movement of the micrometer screw necessary to prevent the flow of water.

A centre limb filled with castor oil indicates when the water is at the same level. A special sight is used to observe the height of the liquid in the centre limb.

When air is flowing through the wind channel there is a considerable reduction of pressure inside the channel and the speeds having once been accurately measured the pitot and static heads can in future be measured by the suction in a small tube placed through the channel wall with its inner end flush with the channel wall. This is done purely for convenience and obviates the necessity of having the tubes always in the channel. This suction tube is placed well forward of the portion where models are tested so that it shall not be influenced by models in the channel.

The suction in this tube is measured by a gauge exactly similar to that used with the pitot and static head.

Information most often required is of lift and drag.

Method of Testing a Model

Any model which is to be tested is placed in the centre of the working (square) portion of the wind channel. A door is placed in the side of the channel at this position for the operator to get in and out. The model is supported entirely on balances by means of which the forces on it with the air flowing can be measured accurately.

The main balance chiefly in use at the National Physical Laboratory and R.A.E. has been designed at the N.P.L. and is made by the Cambridge Scientific Instrument Co.

A single post passes through the floor of the wind channel and terminates at the centre of the wind tunnel. Below the floor of the channel this post rests on a single cone and cup pivot and is supported from a pedestal. The post is continued downwards below the pivot and at its lower end carries counterpoise weights so that it shall not be top heavy.

At the point where the central post rests on the pivot it is enlarged into a

conical portion. Into this conical portion exactly in line with the point of the pivot are screwed three arms mutually at right angles, each arm being counterbalanced. The horizontal arms are set parallel and at right angles to the wind direction. One of the horizontal arms which is at right angles to the wind is used to prevent the balance spinning round on its pivot. It is secured to the pedestal of the balance by means of a light strut and a C spring which, while they prevent it rotating, do not prevent it rocking up and down. The model to be tested is attached to the top of the post inside the channel in a vertical position, for example, if a wing were being tested the spindle would be screwed into one tip with the leading edge of the wing facing the inlet end of the channel. The top portion of the balance rotates on the bottom portion so that the model can be rotated in the channel causing the air to strike the wing at any desired angle of incidence. The angle is indicated by a scale on the balance where the top portion rotates. With the model in this position the counterpoise weights on the balance arms are adjusted so that the balance is exactly vertical.

The wind is now turned on and if the model is not checked it will be blown backwards down the channel and at the same time sideways towards one wall of the channel; the force tending to blow it back along the wind being the drag or resistance, and the force tending to blow it to one side being the lift. These tendencies of the model to move backwards and sideways are checked by placing weights at the ends of the horizonal arms screwed into the balance below the floor of the channel.

The magnitude of the weights necessary measures the lift and the drag of the model.

With this method of testing, unless very great care is taken in setting up the balances and so forth, considerable errors may be introduced. Therefore the method I am about to describe has generally superseded this one.

In this later method of testing the model is placed in the channel in a horizontal position, *i.e.*, in an ordinary flying attitude. The tail of the model rests on the top of the balance and the front of the model is supported by thin wires from an auxiliary balance placed on the roof of the channel. With this method of testing the angle of incidence can be altered by winding these wires up and down on a winch which is part of the auxiliary balance.

This auxiliary balance measures vertical forces only, *i.e.*, lift. I have not previously mentioned it, but the main balance previously described can also be made to measure vertical forces by inserting two additional arms which are counterpoised by weights to support it. Thus the total lift of the model is the sum of the lifts measured on each of these balances.

The drag of the model is measured as before.

With the main balance described there is one unfortunate thing, namely, that inserting the extra arms to measure vertical forces with the main balance alters the angle of incidence of the model in the channel so that the model has to be re-set more frequently.

The angle of the model is measured by sighting it against a protractor screwed to the further wall of the channel. This protractor has a long straight edge and a sighting strip is placed on the model. If the model has not a flat surface on which to place this sighting strip, then some form of shaped block must be provided which will rest on the model always at the same angle. In order to alter the angle of the model it is necessary to stop the wind, set the protractor and re-sight. A refinement has been devised by the R.A.E. which enables the model angle to be altered without stopping the wind.

A small telescope traverses the window horizontally and vertically outside the channel door, which is provided with a glass window so that the model can be viewed through the telescope. This telescope is provided internally with a

hair line, and can be rotated by means of a worm so that the hair line takes up any desired angle. A fine line is drawn on the side of the model in any convenient position, and all that has to be done to set the angle of the model in the channel is to operate the winch so as to bring the two lines parallel when viewed through the telescope.

One thing is to be noticed. The model is almost invariably placed in the channel upside down. This is done because the lift of the model is often greater than its weight and if the model were the right way up it would rise in the channel, that is, fly, as the wires which support it are very thin and cannot of course hold it down. The model being upside down the lift of course acts downwards, increasing the pull in the wires which therefore never become slack. The lift, of course, has exactly the same magnitude whether it lifts upwards or downwards. Occasionally, when testing, models do lift more than their own weight and I have known them fly down the channel and stick on the wire netting.

So far I have described methods for measuring lift and drag. I have illustrated these methods by assuming a wing to be in the channel. If the wing has a very small chord then a thin rod is secured to the model to take the place of the fuselage. Of course if a complete model aeroplane were being tested this rod would be unnecessary as the fuselage itself would reach to the main balance. Such models as those of fuselages are tested exactly similarly except that the front suspension wires are brought to a single point at the nose of the model.

In addition to lift and drag, information as to the trimming angles of a complete aeroplane is required. This information can be calculated from the forces measured by each balance, but in my opinion is better obtained by pivoting the model at its centre of gravity. In order to do this pivots are arranged in the channel and consist of small hard wire pins attached to a small brass plate which are braced in position inside the channel like piano wires and turnbuckles. Light bearing plates are secured to the model in such a way that a line joining the pivots passes through the centre of gravity of the aeroplane. The model is now rocking about its centre of gravity and tail loads can be measured by supporting the tail by a fine wire attached at its top end to one of the balances. When measuring these tail loads it is not necessary for the model weights to be adjusted so that the model balances as the tail load is first measured with the wind stopped and then again with the wind on, the difference of course being due to the wind.

With the model rigged up in this position the power of the elevators can easily be measured by setting them at desired angles and measuring their effect.

Similarly the effectiveness of a rudder can be measured by setting the model up on other pivots so that it yaws instead of pitches on its pivots.

It has been found that the measured forces and the angles at which they act on an aerofoil are influenced by the restraint on the flowing air exercised by the walls of the channel. Corrections have been devised to allow for this effect on the measured results. The corrections effect the drag, the angles of incidence and the pitching moments. All three become greater when corrected.

This correction, of course, is merely to allow for the restraint of the channel walls and has nothing whatever to do with the scale effect.

Models

Foremost amongst the models tested in wind channels are models of aerofoils. The aspect ratio and dimensions of aerofoils used for test in wind channels has been standardised and is 6. These models must be considerably smaller than the maximum width of the wind channel for two reasons. Firstly, as before mentioned, the speed of the air close to the channel walls is slightly less than

the general speed. Secondly, the restraint of the channel walls on the flowing air affects the forces acting on the model. (Note: Corrections for channel wall interference.) Approximately the scale of the wings must not be greater than .6 of the channel width. The ends of these wings are always left square, any effect of rounding, etc., being taken account of later when considering the design of any specific aeroplane.

The models of these wings are best made from metal as they can then be made with better accuracy and are not affected by the climate. It is very expensive, however, to make these models in metal as it involves either planing and scraping or milling with form cutters, so that they are commonly made of wood. When made of wood, mahogany is generally used, and they are laminated in a special manner.

A baulk of timber is made up by glueing a number of planks together and slices are then cut off at right angles to the glued joints. This method produces a plank which is made up of a number of thin strips glued edge to edge. Models made in this way from good timber will keep without warping or distorting for some considerable time. Occasionally models have been made from wax or plaster of Paris, in which case a thin sheet of metal is used as a foundation.

Models of fuselages and of nacelles, etc., are almost invariably made of wood, although it is not essential; these also are usually laminated as before to prevent distortion and also because the glued joints form excellent datum lines throughout manufacture and afterwards. A datum line such as provided by these glued joints is extremely useful, particularly in the case of rounded models as of course there are no longerons, or rails, or structure of any sort such as there are in the full-scale article. Attempts are nearly always made to represent in some way the engine. This is extremely difficult if cylinder heads project, and becomes practically impossible when air-cooled engines such as the Jupiter are used. The bigger parts of the engine are however represented in some way and the smaller parts, such as valve gear and petrol pipes, are omitted. Nose radiators are always omitted (nearly) and the front of the model is left perfectly solid and flat.

When the modern type of low resistance radiator, such as the Lamblin, is used then often some attempt is made to represent this on the model. This can often be done by making the sections of the radiator from thin sheet. Another way of representing radiators is to test various sorts of wire gauze and then choose one which has a drag approximately to that of the actual radiator.

Models of fuselages are always fitted with windscreens and pilots' heads, as sometimes a windscreen fitted to a low resistance fuselage will cause an enormous increase in the resistance. These windscreens are fitted purely to measure the resistance and no attempt is made to measure their effectiveness as screens for the pilot.

Models of complete aeroplanes are made as complete as possible with some exceptions. The main components such as wings, fuselages, engine nacelles, etc., are made as accurately as possible from solid wood, an undercarriage is always fitted, tail planes, etc., but always all wires are omitted. Wires are omitted because the drag of a wire on a small scale measured in a wind channel is always very much higher than that of the wire in the full-scale machine. Often the drag of a small wire measured in a wind channel at a fairly low speed is four times as it should be. The drag of these wires is calculated from data and added later when the results of the test are being examined by the designer. The drag of R.A.F. wires, swaged rods, etc., has been very accurately determined by careful experiments on a large scale so that there is no difficulty in calculating their drag. The struts used in the model are often made to scale, but here again the drag of a small scale strut at a small wind speed may be many times greater than it should be, so that it is advantageous to use the

smallest convenient size of R.A.F. wire to hold the model together. The drag of these R.A.F. wire struts can be calculated and corrections can be made by the designer to allow for the drag of the proper struts which also can be calculated.

In addition to the errors due to scale effect it is extremely difficult to make small struts accurately, and of course badly made struts usually have a higher resistance than they should. This error is eliminated by using R.A.F. wire the sizes of which are correct within very small limits.

Control surfaces are often tested for effectiveness and the forces necessary for operating these control surfaces are at the same time measured. For tests of this sort the model is set up in any convenient way which the wind channel operator thinks suitable. No standardised methods have been evolved. Rudder and elevator controls are tested in the manner which I mentioned earlier when describing how tail loads were measured by setting the model up on pivots at its centre of gravity. This method of course determines only their effectiveness. If it is required to measure the forces necessary to operate the elevators, then a large scale model of the tail plane is made with elevators delicately hinged. This tail plane is secured in the channel in any convenient way and a wire is taken from the elevator to one of the balances and the force necessary to hold it at any angle can then be measured. The control forces on a rudder can be measured similarly by making up a large fin and rudder and testing them the same way. It is not usual to test the rudder of an aeroplane in this way unless the machine is very large or is a twin-engined machine, in which case it is often necessary to provide a rudder which will hold the aeroplane on a straight course with one engine shut down. Ailerons are tested by making up a model of one half span of one wing, again with an aileron delicately hinged. This wing is, in addition, provided with a hinge pin which is on the centre line of the machine and pointing down wind. This wing tip is supported by a wire from one of the balances and when the aileron is moved the rolling forces it produces can be measured on the balance to which the wire is attached. This rolling moment is measured with the wing at different angles of incidence and with the aileron moving through its full angular range. To measure the control force the tip of the wing is held securely in the channel and the wire from the balance is attached to the trailing edge of the aileron and the force necessary to hold it at various angles is measured on the balance.

Interpretation of Results

Assuming that one has made very accurate measurements of the characteristics of a model, then the problem arises as to what they mean or whether they mean anything at all. The interpretation of the results is usually left to the designer, who tries to think what they mean. In the first place, as previously mentioned, there are an enormous number of small differences between a small model and a big aeroplane, such as:—

1. An aeroplane wing is made up from ribs which are the correct shape, but obviously the fabric sags between the ribs. Careful experiments have been made and apparently the sag is insufficient to cause any appreciable difference in the characteristics of the wing.
2. An ordinary fabric covering must be secured to the framework, in the case of a wing by sewing or taping, or in the case of a fuselage by lacing. The exact effect of all this, and other things such as bolt heads, I do not know.
3. As previously mentioned, going from a model to a full-scale machine you find that the elementary laws of hydrodynamics do not hold good accurately, *e.g.*, one would expect the maximum lift from a wing to be proportional to its area. Unfortunately this is not so and the stalling speed of an aeroplane may be slightly different from that expected from

tests in a small wind channel. This is a constant source of trouble as of course the stalling speed of an aeroplane must be kept within limits and the appropriate wing area provided.

4. Similarly the drag of a wing is not in proportion to its area, the drag being almost invariably lower than that predicted by the wind channel. Here again with any new wing there is a certain amount of speculation as to its full-scale drag.

5. I do not know in what exact manner the drag of a fuselage changes in going from model to full-scale, but in any case where there are any projections from the engine, particularly in the case of radial air-cooled engines, it is extremely difficult to predict what the actual drag of the fuselage and the engine will be.

6. The drag of a strut is very much smaller full-scale than when tested in the wind channel. Often a small strut tested in a wind channel will forecast a drag three or four times as great as that experienced on a full-scale machine.

Wheels, tail planes, rudders, and all other small parts suffer likewise a reduction in drag.

The designer endeavours to predict how much reduction can be expected when going from small model tests to full-scale. A certain amount of data is obtainable on well known wings and here it is possible to make a fairly accurate forecast of the reduction to be expected. The same applies in the case of struts. As previously mentioned, the struts of a modern aeroplane are sometimes left out as it is more accurate to calculate the drag of these struts than it is to measure it. When struts are essential to hold the model together then R.A.F. wire is sometimes used because the drag of a R.A.F. wire is accurately known, whereas the drag of a small strut, the section of which is probably doubtful, is extremely difficult to predict.

As regards trimming angles, I have found that usually these can be predicted with fair accuracy from wind channel tests when the machine is gliding. Of course when the propeller is running the trimming angle is very much altered because the slipstream from the propeller causes extra downwash on the tail plane, which of course tends to make the machine put its nose up.

Experiments are often made with a small propeller to scale running in front of the machine. When testing like this the propeller is supported independently and is not connected with the machine in any way, the sole object of the experiment being to determine the effect of the slipstream on the aeroplane. I have said that the propeller is never connected to the aeroplane. In saying this I am not quite truthful as occasionally a motor has been fitted inside the model as it would be in a full-scale aeroplane. There are enormous difficulties to be overcome when doing this, chiefly because it is almost impossible to design a motor small enough to be put inside the machine, and can only be done with a specially designed one of small dimensions and a very large model.

As regards controls, I think here the wind channel can be relied upon to give fairly accurate predictions as to the behaviour of controls in the air, both as regards effectiveness and also the forces which the pilot will have to exert to operate them.

Other Wind Channels

There are a great number of wind channels in use in England, but I think they are all of the N.P.L. type and are generally very similar to the Westland channel, which is in itself a copy of the N.P.L.

The type of channel generally as used on the continent differs rather from

the English type in many respects. It is known as the "open type," the air being drawn across a room.

Latest types.—In order to decrease the scale effects it is necessary to increase either the air speed in the channel, the size of the model, or the density. In England the tendency has been to build larger channels and to increase the speeds. A size of channel commonly in use is 7ft. by 7ft. cross section, and one, the Duplex channel at the N.P.L., is 14ft. by 7ft.

The operating expenses of such a channel are exceedingly high as of course, apart from the channel itself, very large and expensive models are required. Actually a lot of experimental work has been carried out on a fifth scale model of the Bristol Fighter.

America.—In this country a channel has been built of the closed circuit type in which the returning air flows through a special channel provided, and by means of a compressor the air pressure inside can be increased to as much as 20 atmospheres, the density of course being twenty times as great and the forces acting on the model also twenty times as great. This means that at a fairly high speed one gets approximately full-scale results.

This channel is still to a certain extent experimental, but very interesting results have been obtained, particularly with regard to the minimum drag of aerofoils, etc., and to the maximum lift obtainable from any aerofoil, the results indicating that in some cases aerofoils commonly known as high lift produce little or no more lift than others which in an ordinary small channel appear to have a comparatively small maximum lift.